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User-Centred Design and Evaluation of Interactive System Assisting the Mobility of People with Intellectual Disability

Aymen Lakehal

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Thèse de doctorat

Pour obtenir le grade de Docteur de

l'UNIVERSITE POLYTECHNIQUE HAUTS-DE-FRANCE et de l'INSA HAUTS-DE-FRANCE

Sciences et Technologies de l'Information et de la Communication
Spécialité : Informatique et Applications

Présentée et soutenue par **Aymen LAKEHAL**

Le 12/07/2022, à Valenciennes

Ecole doctorale : Ecole Doctorale Polytechnique Hauts-de-France (ED PHF n°635)

Unité de recherche : Laboratoire d'Automatique, de Mécanique et d'Informatique
Industrielles et Humaines (LAMIH - UMR CNRS 8201)

Contribution à la conception centrée utilisateur et à l'évaluation d'un système interactif aidant la mobilité de personnes en situation de déficience intellectuelle

JURY

Président du jury : Girard, Patrick. Professeur. Université de Poitiers

Rapporteurs : Krömker, Heidi. Professeur. Université TU Ilmenau
Bellik, Yacine. MdC HDR. IUT d'Orsay, Université Paris-Saclay

Examineurs : Courbois, Yannick. Professeur. Université de Lille
Uzan, Gérard. Ingénieur de Recherche. Université Paris 8

Directeur de thèse : Kolski, Christophe. Professeur. UPHF

Co-encadrant : Lepreux, Sophie. MdC. UPHF

Membres invités : Lenger, Eric. Directeur Informatique. Udapei du Nord
Pudlo, Philippe. Professeur. UPHF

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Research unit : Laboratory of Industrial and Human Automation control Mechanical engineering and Computer science (LAMIH – UMR CNRS 8201)

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Uzan, Gérard. Research Engineer. University of Paris 8

Thesis director : Kolski, Christophe. Professor. UPHF

Co-supervisor : Lepreux, Sophie. Associate Professor. UPHF

Invited members : Lenger, Eric. IT Manager. Udapei du Nord
Pudlo, Philippe. Professor. UPHF

I would like to dedicate this thesis to my loving parents, Djahida & Rachid, and my siblings,
Amani, Amine, Housseem & Imene, for their unconditional love <3
To my lovely doggy Lilou and my Horse Virevolte, my small family <3

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Keywords: Wayfinding, Navigation Assistance, Intellectual Disability, Augmented Reality Glasses, Human-Computer Interaction (HCI).

Mots-clés: Wayfinding, Assistance à la Navigation, Déficience Intellectuelle, Lunettes de Réalité Augmentée (AR), Interaction Humain-Machine (IHM).

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Université Polytechnique Hauts-de-France

Le Mont Houy

F-59313 Valenciennes Cedex 9

The roots of education are bitter, but the fruit is sweet. Aristotle

Abstract

This doctoral thesis, in Human-Computer Interaction (HCI) field, addresses the question of mobility assistance for people with intellectual disability (ID). The main goal is to use a user-centred approach to design and evaluate a navigation aid system (NAS). Navigating independently through the environment is necessary to participate in different social activities and thus, it represents a key factor of social inclusion. Usually, people with ID encounter various navigation challenges, for instance: (1) Memorise a familiar path. (2) Remember and execute complex navigation instructions. (3) Poor adaptation when conditions change due to bus stop changes for example. In order to understand the human navigation behavior and different systems designed for this purpose, the state of the art was explored aiming to identify key elements to define the main research questions:

- What could be the contribution to improve human spatial navigation skills?
- How the spatial knowledge acquisition could be improved?
- How could an adapted navigation aid system be designed for people with ID?

In this work, the pedestrian navigation behavior is explained using a detailed model of wayfinding, which is the cognitive process behind human navigation behavior. This model is designed to highlight people needs during the navigation task and offers an opportunity to design NAS to address them more efficiently. In addition, an ontology, about human navigation, was developed to define different key words used in this navigation field including the previous model. This ontology plays an important role in establishing a strong communication between different stakeholders that collaborate in this research field (researches in psychology, human-computer interaction, etc). Furthermore, new augmented reality (AR) glasses were tested to design a navigation aid system, and were compared to a smartphone. This comparison helped to investigate the effect of the device on navigation performance and memorisation of road landmarks. At the end, the designed system was adapted during co-design workshops gathering people with ID and professionals of the institution Udapei - IMPRO (<http://www.udapei59.org/>). The system was tested considering two navigation tasks: (1) road crossing and (2) path following. Different aspects of road safety were considered during the co-design of the system. The obtained results are promising, and the users feel comfortable and confident about using the AR glasses on a daily basis when travelling to new destinations. This positive feedback is encouraging to upgrade the system and extend its scope to cover the entire spatial knowledge acquisition process (all states of the Wayfinding Model).

Keywords: Wayfinding, Navigation Assistance, Intellectual Disability, Augmented Reality Glasses, Human-Computer Interaction (HCI).

Résumé

Cette thèse de doctorat, dans le domaine de l'interaction humain-machine (IHM), aborde la question de l'aide à la mobilité pour les personnes présentant une déficience intellectuelle (DI). L'objectif principal est d'utiliser une approche centrée-utilisateur pour concevoir et évaluer un système d'aide à la navigation (SAN). La navigation autonome dans l'environnement est nécessaire pour participer à différentes activités sociales et représente donc un facteur clé de l'inclusion sociale. En général, les personnes atteintes d'une DI rencontrent divers problèmes de navigation, par exemple : (1) Mémoriser un chemin familier. (2) Se souvenir et exécuter des instructions de navigation complexes. (3) Adaptation limitée lorsque les conditions changent en raison d'un changement d'arrêt de bus par exemple. Afin de comprendre le comportement humain en matière de navigation et les différents systèmes conçus à cette fin, l'état de l'art a été exploré dans le but d'identifier les éléments clés permettant de définir les principales questions de recherche :

- Quelle pourrait être la contribution à l'amélioration des compétences humaines en matière de navigation spatiale ?
- Comment l'acquisition de connaissances spatiales peut-elle être améliorée ?
- Comment un système d'aide à la navigation adapté pourrait-il être conçu pour les personnes souffrant d'une déficience intellectuelle ?

Dans ce travail, le comportement de navigation des piétons est expliqué à l'aide d'un modèle détaillé d'orientation, wayfinding, qui est le processus cognitif à l'origine du comportement de navigation humain. Ce modèle est conçu pour mettre en évidence les besoins des personnes pendant la tâche de navigation et offre la possibilité de concevoir des SAN pour y répondre plus efficacement. En outre, une ontologie, sur la navigation humaine, a été développée pour définir différents mots clés utilisés dans ce domaine de la navigation, y compris le modèle précédent. Cette ontologie joue un rôle important dans l'établissement d'une communication forte entre les différentes parties prenantes qui collaborent dans ce domaine de recherche (chercheurs en psychologie, en interaction humain-machine, etc). De nouvelles lunettes de réalité augmentée (RA) ont été testées pour concevoir un système d'aide à la navigation, et ont été comparées à un smartphone. Cette comparaison a permis d'étudier l'effet du dispositif sur les performances de navigation et la mémorisation des points de repères. Au final, le système conçu a été adapté lors d'ateliers de co-conception réunissant des personnes avec une DI et des professionnels de l'institution Udapei - IMPRO (<http://www.udapei59.org/>). Le système a été testé en considérant deux tâches de navigation : (1) traverser une route et (2) suivre un chemin. Différents aspects de la sécurité routière ont été pris en compte lors de la co-conception du système. Les résultats obtenus sont prometteurs, et les utilisateurs se sentent à l'aise et confiants dans l'utilisation quotidienne des lunettes de réalité augmentée lorsqu'ils se déplacent vers de nouvelles destinations. Ce retour positif nous encourage à améliorer le système et à étendre son champ d'application pour couvrir l'ensemble du processus d'acquisition de connaissances spatiales (c'est-à-dire en couvrant les états du modèle Wayfinding).

Mots-clés: Wayfinding, Assistance à la Navigation, Déficience Intellectuelle, Lunettes de Réalité Augmentée (AR), Interaction Humain-Machine (IHM).

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Chapter 1

Introduction

Spatial navigation consists of moving through the environment from a location to another one, and with or without an assistance. This definition seems to be clear but did we think about the reason why we are spending this physical and mental effort? The answer could be very simple depending on people needs; they can go for shopping, exercising a sport, just for a walk, visiting new places, meeting their friends and families, or last but not least to work. With the current pandemic crisis Covid-19, humans learnt to perform many tasks from their home even for work when it is possible. Some jobs are less flexible and cannot be assured from somewhere else than the workplace. All these activities and social interactions helps to forge stronger bounds amongst humans and provides a feeling of being part of the society and well included.

People may encounter different challenges while performing pedestrian navigation tasks. The complexity of these challenges could differ according to someone's physical and cognitive abilities. For instance, a healthy young person could find a navigation task very challenging when they are in a hurry, having a decisive meeting and encountering, for example, an unexpected change in the metro lane or road construction. An old person with some health issues could find climbing up stairs very challenging and handicapping. Another one with vision problems [13] may find it challenging too to read road signs or find their path in a crowded street. Someone with memory disease, could be Alzheimer, may find it impossible to remember their way or recognize their surroundings. Or a person with a mental or an intellectual disability (ID) may find it tricky, very stressful and mentally exhausting to navigate through their environment and to cope with unexpected transport changes [75, 6].

By using a user-centred approach, this thesis, in Human-Computer Interaction (HCI), tries to address the question of assisting people with ID (under the class of cognitive or learning disabilities without considering autism, dementia or traumatic brain injury, cf. disabilities

Introduction

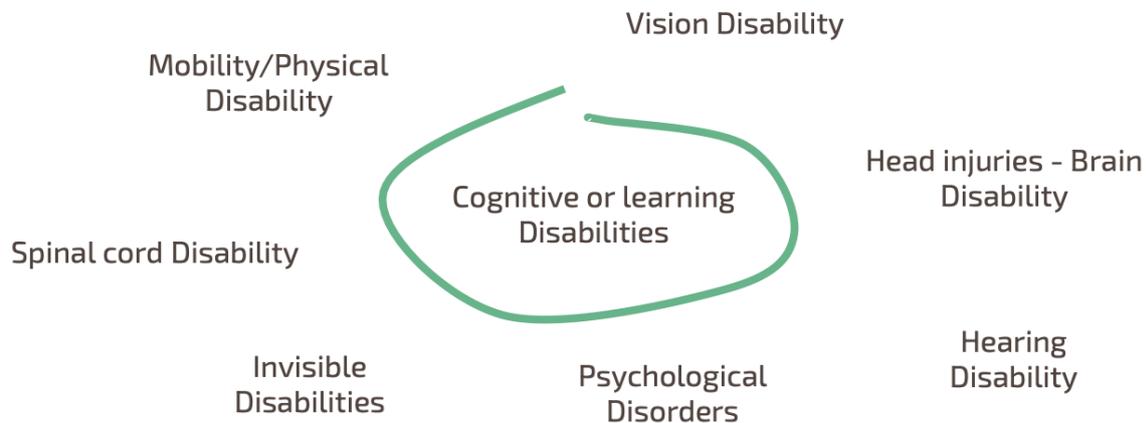


Fig. 1.1 Disabilities classification

classification¹ in Figure 1.1) during their daily navigation tasks. That says this audience may consider spatial navigation very complicated and handicapping for their social lives. This difficulty may imprison them in partial or total isolation far from social activities (going to cinema, work or practicing a sport, etc.) or make them dependent on personal assistance (family member, friend or a professional aid), belonging to their social environment, also called ecosystem in [41, 42].

Valmobile project aims to allow people with ID to navigate their environment more independently and lighten the need of a personal assistance. This project, directed by Pr. Philippe Pudlo, is part of "PIA 3, Accroche Active" funded by the region of "Hauts-de-France". The research team tried to formulate their goals mainly around this question: "how could we help people with ID to navigate more independently through their environment?". In other words, the goal is to develop a system that (1) supports a better spatial knowledge acquisition and (2) offers a comprehensive and adapted user interface. In order to explain more in details the navigation challenges for people with ID and the different studies put in place to address different research questions below, the next paragraphs would illustrate the structure of this thesis.

- How could we design an adapted navigation aid system for people with ID?
- How could we contribute to improve their spatial navigation skills?
- How could we encourage spatial knowledge acquisition?"

To begin, the first section presents the state of art, highlighting related work and relevant definitions. It introduces the spatial navigation, its physical and cognitive components, and

¹Source: <https://www.disabled-world.com/disability/types>

gives an overview of spatial knowledge acquisition mechanisms. Then, it gives a summary of different existing systems designed for the same purpose or similar needs, and concluding with their limitations and the challenges facing people with ID during navigation, which would justify this thesis.

The second section, which represents the scientific contribution, is divided into 4 chapters. Chapter III introduces a new ontology for spatial navigation. It has been created in order to establish a common ground for researchers from different backgrounds (psychology, human-computer interaction, ergonomics, etc.). In this chapter, the approach used to generate this ontology is described. Then, a first scenario-based validation is illustrated as the step one of the user-centred design process. This ontology may represent the basis for an adaptive system that could be designed to keep evolving with the needs of the user. This aspect is discussed in more details in the last section "Conclusion & Perspectives".

The next chapter IV presents the novel wayfinding model of the cognitive part of navigation. This model was created, following a system design orientation, using a state-transition diagram (UML²). It explains the different states of wayfinding task during the navigation and according to the spatial knowledge someone may have at different moments or locations. This chapter enumerates a list of design guidelines that could be considered to design and improve navigation aid systems. A preliminary study was performed to test one specific state "path following" and validate the usability of an augmented reality (AR) new glasses. This second contribution helped to explicit the navigation process and illustrate different steps that could be addressed by a NAS especially for people with ID.

Chapter V is intended to explain in depth the outcomes of a comparative study between AR glasses and smartphone during a navigation task. This study took place in the campus of the University of Kent (Canterbury, UK), and which was funded by two scholarships granted by I-SITE ULNE³. This collaboration aims to answer a part of the first research question related to the system design. It helped to investigate the difference between these two devices and their effects on spatial knowledge acquisition for neurotypical population. In this chapter, several performance and usability metrics were captured to quantify this difference. One of the main outcomes of this study helped to assess if a device could offer better experience than the other one. According to this outcome, one device was selected to pursue the last study with the targeted audience, people with ID.

Furthermore, the chapter VI illustrates the approach used to design the last study involving people with ID and their professional trainers. This chapter explains how the system was adapted during couple of co-design (participatory design) workshops gathering the users and

²Unified Modeling Language

³Fondation I-SITE Université Lille Nord-Europe (ULNE) - <http://www.isite-ulne.fr/index.php/en/home/>

Introduction

different stakeholders. These workshops were held under the collaboration agreement with Udapei institution (a division of Unapei in the North department of France) and precisely with the IMPRO organism (Institut Médico-Professionnel: Medical and Professional Institution). Furthermore, this last chapter shows how the approach was flexible and adaptive to the needs of the users, and how it has included the different puzzle pieces illustrated by the previous chapters: (1) from different concepts of the ontology used to adapt the communication language, to (2) considering the wayfinding model and also (3) while selecting AR glasses to design the navigation assistance system.

Finally, the conclusion highlights the key findings of this thesis and gives an overview of how these findings added up to achieve designing a system that supports better people with ID during their navigation. A set of perspectives is discussed in order to present possible extensions and improvements for the designed system, such as: considering unforeseen events that affect the navigation, different states of Wayfinding Model and being adaptive to spatial knowledge level.

Part I

State of Art

Chapter 2

Wayfinding & Navigation Aid Systems (NAS) for pedestrians in Urban Mobility

2.1 Introduction

Nowadays, people use more and more often Navigation Aid Systems (NAS) for their mobility. Those systems are based on Global Positioning System (GPS) and best trip algorithms. They may help to provide detailed trip planning instructions (for example mobile applications for route planning). This type of aid might guide people through their environment to reach their destination. Unfortunately, it may lead to decrease the use of their navigation skills due to what we call *Blinded Navigation*: « the way of navigating the environment focusing on the received guidance from different assistance tools and losing the awareness of the surroundings and thus the lack of the ability to remember the path [59] ». For instance, one of these skills is to develop a cognitive map of the surroundings [33]. Thus, it causes less spatial awareness, separating them from the real world. The current research aims to introduce the new concept of wayfinding state awareness which may help to design adaptive interaction for mobility assistance. By considering the survey knowledge the users have, the system could provide better active assistance. Moreover, the goal of this work is to help with their navigation skills development and improve the spatial acquisition knowledge about the environment knowledge. To summarize, the main question being raised is: how could we design an adapted navigation aid that can consider different states of the wayfinding process?

A literature study may help to understand the wayfinding process, which represents the cognitive part of the navigation task. It will also allow comparison of existing navigation aid systems for pedestrians regarding the interaction platform used and the inclusion of different states of the wayfinding process.

2.2 Navigation: Wayfinding and Locomotion

Navigation is the task of people moving through their environment to achieve a destination. It may be understood to include the two components of locomotion and wayfinding [81, 82]: (1) Locomotion which is the movement of one's body around an environment, coordinated specifically to the local or proximal surrounds - the environment is directly accessible to the sensory and motor systems at a given moment. (2) Wayfinding which is the goal-directed and planned movement of one's body around an environment in an efficient way. It requires a place goal, a destination one wants to reach and consists to determine and follow a path or route between an origin and a destination [34–36] (cited by [60]). Frequently, this destination is not in the local surrounds. Wiener and his colleagues [114] have elaborated a taxonomy for different wayfinding tasks based on the level of involved spatial knowledge (more details in the next section).

To go back in time and understand the development of the wayfinding and these navigation-related concepts, Delgrange in his thesis [26] has done a great job summarising it. He stated that first work interested in the capacity to find a path appeared in the middle of the XIX century. Fowler [30] was one of the first authors to discuss these cognitive processes. He called *locality* this capacity to recognize the surrounding and move towards a destination.

Boring, Griffin, Lord and Tolman (respectively [14, 37, 66, 107]) were interested, from the beginning of the XXth century, in mental cards of the environment which created cognitively by people during navigation. Tolman [107] introduced this concept based on his famous experiment: "Rat's Maze". By using an animal model (a rat), he observed successive attempts of rats to cross the maze in order to extend the findings to human cognitive behaviour. In this experiment, rats managed to get out of the maze progressively faster and with less mistakes over the attempts/time. According to this author, these results demonstrates that rats are capable of developing a cognitive map of the maze. The future work on cognitive cards has focused on its construction without considering the use of this card during navigation.

A holistic view on navigation reappeared in the second half of the XXth century with the first use of « wayfinding ». This concept emerged into the literature about urbanism thanks to the work of Lynch [67, 68]. This author defined the wayfinding as the action to find a path based on the image of the environment that someone has built, by their direct perception and by the information they memorised before. This mental image is then used to analyse spatial cues and guide the navigation progressively along the path. Many authors have adopted, after this period, a more practical approach in regard the exploration of wayfinding and the analysis of human behavior and related processes to mental cards construction [29, 78].

The wayfinding was not directly picked up in the field of cognitive science contrary to cognitive/mental map concept. However, at this period of time, many studies indicated that

people are capable of navigating through their environment without a prior mental map, including complex environments like natural or unconstructed ones [52], or conversely, a subway network [15]. Kaplan [52] mentions also that the knowledge of the environment includes only the information contained in a map. Bronzaft and their colleagues [15] show that New York subway passengers use particularly signs and audio announcements to navigate through, instead of maps. This brings different authors to conclude that mental map construction is multi-factorial and it develops during the navigation [24].

According to Kaplan [53], this idea stresses the need to explore not only representational aspects of spatial cognition, but to extend also to functional aspects related to human interaction with their environment. All this contributes to bring the wayfinding to the field of cognitive science and environmental psychology. The wayfinding as suggested by Lynch [67] appears in the field of cognitive science in a study by Kaplan [52]. Its theoretic foundation is defined by Passini [91, 92]. Passini [92, 93] distinguishes the mental map concept from the wayfinding as a cognitive and behavioural dynamic process to reach a destination. They define the wayfinding as spatial-problem solving allowing someone to navigate towards their destination through the environment. In particular, if the initial problem of wayfinding is spatial, its solving consists of the set of behavioural actions performed along the way from the depart point to the destination [92].

2.3 Wayfinding Taxonomy

Figure 2.1 provides a representation of this taxonomy. Three levels of spatial knowledge were considered according to [114]: “(1) knowledge about a point in space (e.g., a landmark, a destination), (2) knowledge about a sequence of points (i.e., a path to a destination, often referred to as route knowledge), (3) knowledge about an area (i.e., knowledge about the spatial relation of at least two points, often referred to as survey knowledge).” In this taxonomy, an undirected wayfinding refers to a state without a specific destination and according to the survey knowledge one can change from a pleasure walk when the environment is familiar and an exploration state when it is not. When the destination is defined, Wiener and his colleagues introduce the directed wayfinding which can be divided, according to the level of spatial knowledge, into: (1) destination search while the target location is unknown, it is considered informed or uninformed search depending on the knowledge about the environment. (2) When the destination location is known, the navigator will proceed to a path following task if the path is known or, in the other case, to a path finding task. (3) Path finding which is also divided into: path planning while the environment is known or a path search while it is not.

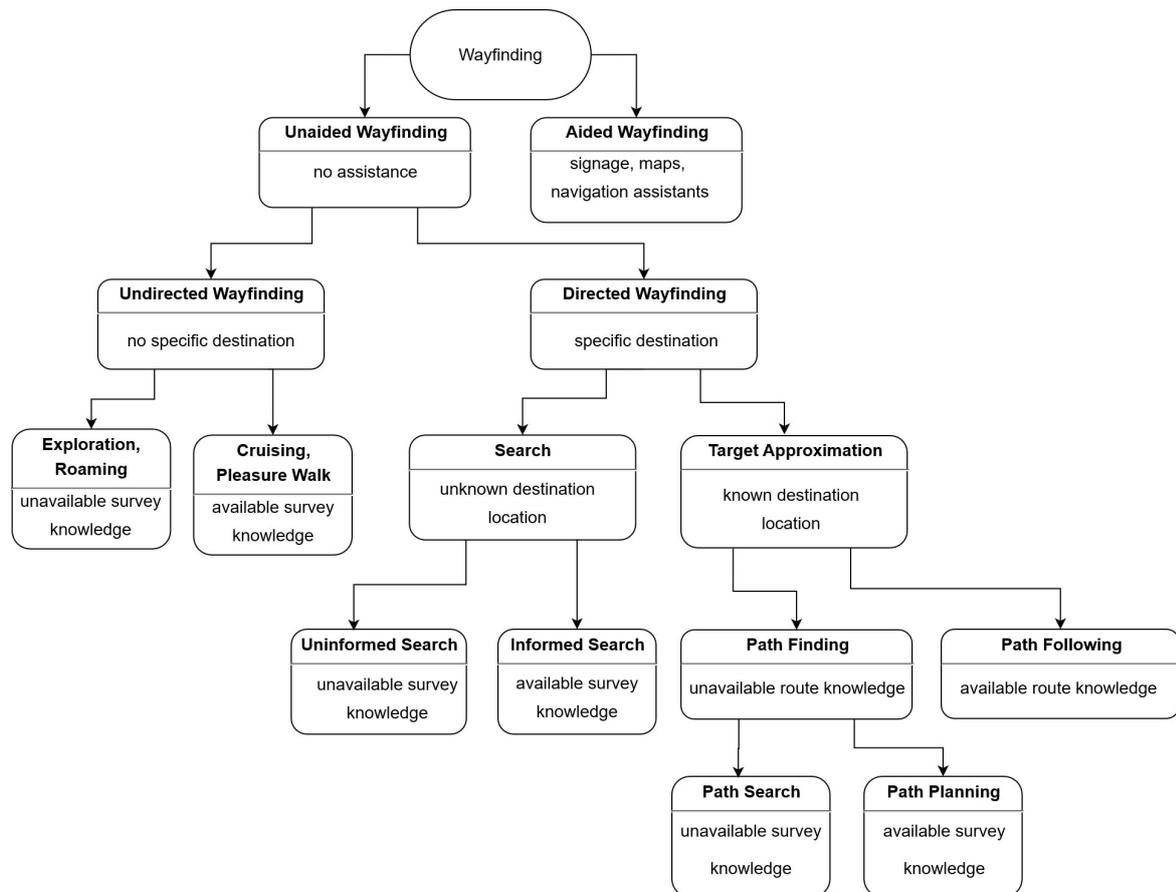


Fig. 2.1 Wayfinding Taxonomy by Wiener and his colleagues [114]

2.4 Spatial Knowledge Acquisition

According to [69], the hippocampus¹ and the brain growth positively correlates with the amount of navigation skills' use. The less people use their navigation skills, the less their hippocampus is developed. As a result, it may cause cognitive deficits during normal aging [56]. People tend to keep focusing on instructions change instead of observing their surroundings. Indeed, current NAS may help people with their wayfinding task, for instance: including route planning and following more often using auto-generated instructions. Those instructions drive the navigators through their environment in a blinded navigation. Thus, they influence negatively their spatial knowledge acquisition [64].

According to [103], using landmarks, which are salient entities in the environment, helps to improve the survey knowledge during the wayfinding task. These authors suggested a theoretic model explaining the development process of this knowledge acquisition. They

¹The hippocampus is a specialized region in the brain to navigate the spatial environment [69].

found that the representation of this knowledge about a specific area, goes progressively from knowing landmarks then paths to a global survey knowledge. Montello in [81] called it: “the dominant framework” considering the big influence of this model on the literature. [50] describes landmarks recognition as: People tend to recognize a landmark by its importance in the environment in terms of size, shape or colour.

2.5 NAS & Spatial Knowledge Acquisition

Mobile interactive systems are becoming more and more common tools in assisting pedestrian mobility. For example, more and more pedestrians are using smartphones equipped with navigation software, particularly to navigate unfamiliar places. Although such tools are considered very useful, several studies have shown that this form of passive assistance does not help pedestrians memorize journeys. Nor do they help them become familiar with the environment [49, 56, 69, 10]. Indeed, on smartphones, the most common navigation systems support wayfinding using directive instructions. As shown by Gardony et al., they do not provide opportunities to develop spatial skills and reduce spatial awareness [33]. These effects can have a negative impact on cognitive abilities of their users, especially with very frequent use. On this subject, studies on taxi drivers [69] have shown that enhanced navigation skills are positively correlated with increased activity and gray matter in the hippocampus in people’s brain. Konishi and Bohbot also showed that reduced navigational skills can contribute to cognitive decline during normal aging [56].

As reported by Ruginski and colleagues [99], traditional map-based automated navigation assistance can have a negative effect on spatial transformation abilities. They observed negative impact, in case of changes in perspective, and on environmental learning [99]. Indeed, a study by Meneghetti and colleagues has shown that navigation learning involves only visuo-spatial abilities, and not verbal ones [73]. This important result explains why automated navigation system that do not expand the user’s visuo-spatial skills, lead to degradation in spatial knowledge acquisition [90].

For several years, researchers have been interested in how to integrate landmarks into the design of navigation systems. It is considered that landmark-based navigation systems can help improve the user’s knowledge of the environment during wayfinding tasks [103]. Work from Montello [81] showed that landmarks are salient entities in the environment and they can help improve the user’s survey knowledge during wayfinding tasks: the representation of knowledge about a specific location, goes progressively from knowing landmarks, then paths, and finally to a global survey knowledge. Our work is motivated by these findings. Our aim is to study the effects of landmark-based navigation systems, deployed on smartphones or

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AR glasses, in helping users learn how to navigate the environment ultimately without the need for wayfinding technology.

The spatial knowledge acquisition in pedestrian navigation has been investigated by a limited number of studies, comparing different interaction modalities or devices. Huang and colleagues [46] explored the effects of smartphone map-based navigation, through different interaction modes: (1) visual map, (2) voice or (3) augmented reality (through the smartphone). They found no significant difference on spatial knowledge acquisition. The specific work did not explore the effects of landmark-based navigation focusing only on the use of smartphones as interaction devices. A similar study [97], comparing the use of digital maps, voice, and augmented reality interfaces for navigation assistance, found that AR was less effective in users navigation. That work did not explore the acquisition of knowledge through the navigation task, while their focus was primarily on the use of smartphones as the main interaction device. In this study [49], GPS users traveled longer distances and made more stops during a walk than map users and direct-experience participants. Also, GPS users traveled more slowly, made larger direction errors, drew sketch maps with poorer topological accuracy, and rated wayfinding tasks as more difficult than direct-experience participants. While Cheng and colleagues [19] aimed at thoughtful navigation for pedestrians by improving engagement through Augmented Reality. One more study [112] compared between 5 apps installed on a smartphone (cf. Figure 2.2): north-up map, forward-up map, compass, augmented reality and radar. It addressed the user perception of tools and the interface performance but without considering the navigation or memorisation performance.



Fig. 2.2 The five navigation tools [112]

The study [85] was aimed at questioning people expectations for their future pedestrian navigation and the potential acceptability of several futuristic sensory navigation devices that were imagined based on recent HCI research, patents or emerging market. The results highlighted two main concerns for relying more often on walking and using pedestrian navigation devices in the future: the possibility to look around at the surroundings and the safety along the path.

Kamilakis and colleagues [51] propose a mobile application which addresses practical requirements of public transport users (visualization of nearby transit stops along with timetable information of transit services passing by those stops). In their paper, they study the utility and experience perceived by users interacting with mobile augmented reality (MAR) vs. map-based mobile application interfaces (cf. Figure 2.3). MAR have been shown to offer an enjoyable, intuitive interaction model. This demonstrates its potential of directly linking digital content with the user's physical environment thereby enabling the experiential

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Fig. 2.3 (a) The MAR interface; (b) the map interface; (c) transit services' schedule information for a selected bus stop [51]

exploration of the surrounding elements. The offering of improved sense of orienteering relatively to surrounding physical elements (e.g. unambiguous interpretation of the direction towards a Point of Interest) should be regarded as another strong aspect of sensor-based MAR applications. The authors conclude MAR interfaces still need to resolve major usability issues until they can be regarded as indisputable substitute of traditional map-based interfaces. Most likely, emerging devices like smart glasses (which involve principally different methods for interacting with digital content) would affect the quality of experience perceived by users.

Using image-based navigation system, Walther-Franks and Malaka in [111] suggest a design of an augmented photograph-based app on a smartphone and compares it to a map-based mobile app (cf. Figure 2.4). This study did not address any spatial navigation skills but showed one interesting result regarding the degree of attention required by the user. Indeed, the results showed that the users experienced a lower demand to keep looking at the image-based system because they were alerted when a new message was fired. Thus, this solution might be less distracting and offers more time to focus on the environment.

Amirian and colleagues [8] designed an AR navigation system on a tablet recognizing landmarks from the images taken by the system and superimpose navigational objects

2.5 NAS & Spatial Knowledge Acquisition



Fig. 2.4 Screenshots of the prototype interface with arrow and line visualisation; The Destination 6 interface with a 2D map in pedestrian mode [111]

(orientation arrow and distance information) (cf. Figure 2.5). This system was compared to turn-by-turn map-based navigation system. As explained by the authors, their system demonstrated significant improvements in acquiring local knowledge.

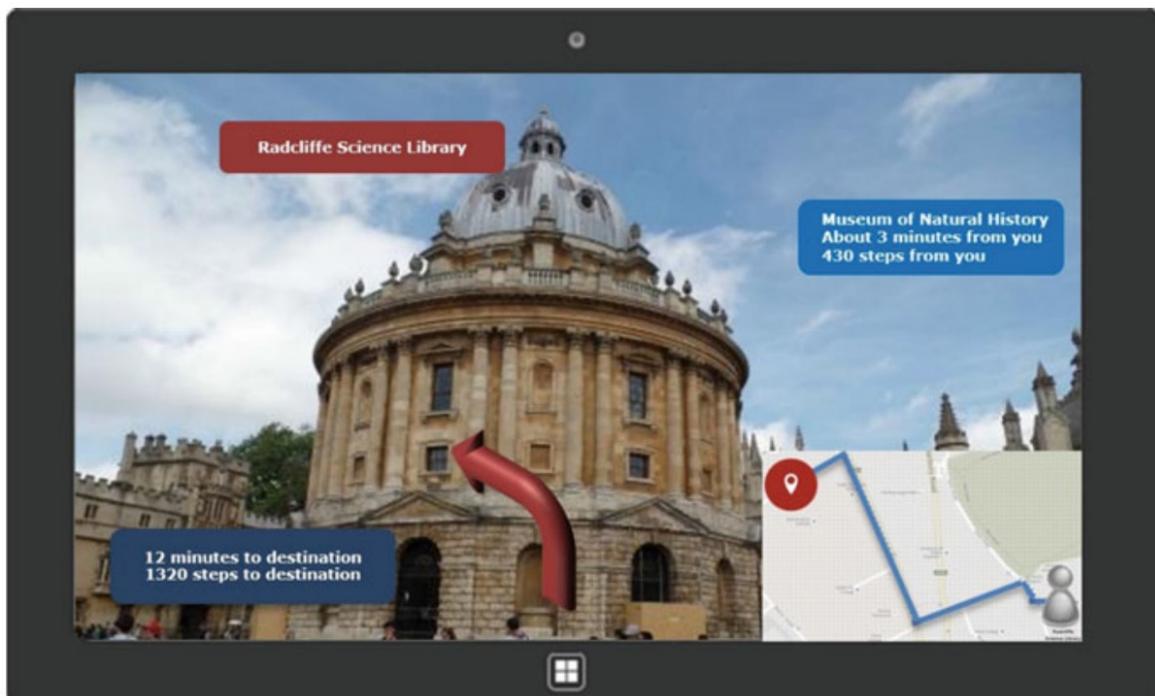


Fig. 2.5 The implemented system uses landmark based navigation to instruct the user [8]

These early attempts in exploring the effects of technology assisted navigation, in spatial knowledge acquisition have not so far produced results that can lead to practical advice. To the best of our knowledge, there are no studies that addressed the spatial knowledge acquisition using AR glasses and smartphones with a landmark-based navigation system. With respect to methodology, there are no studies considering the ability to mentally rotate objects and imagine locations from other perspectives (both known as spatial transformations), which is positively related to environmental learning, during a memory test task.

2.6 Comparison of Current Navigation Aid Systems

Of course, smartphones equipped with navigation software already make it partially easier for pedestrians to navigate in the city. However, studies show that this type of passive assistance does not make it possible to memorize journeys and appropriate the environment [49, 56, 64, 116, 69, 99]. The current navigation experience, based on GPS, presents one major drawback: Wayfinding using directive instructions leads to decrease navigator skills. Thus, it may reduce the development of cognitive maps causing less spatial awareness [33].

The Table 2.1 shows a comparison made between different navigation aid systems from the literature. The attributes below are used:

- **Name of the designed system:** to precise if the system has a name.
- **Pedestrian Navigation Mode:** if in the current study, the pedestrian mode is considered or not.
- **Type of Navigation:** indoor or outdoor.
- **Interaction Support:** represents the device used to test the suggested system, for example smartphones, smartwatches, augmented reality glasses, etc.
- **Landmarks suggestion:** it is a “Yes” if the guidance given highlights landmarks found in the navigation path.
- **Context (Wayfinding task awareness):** The context may be used dynamically to tailor the behaviour of the system or its response to patterns of use [27, 28]. In our current work, the context of the mobility represents mainly the wayfinding state of the user during the navigation. For example, when the user is in a path following state (cf. Figure 2.1), the context attribute will have the value: path following state. This attribute in the comparison table reflects the fact that the system considers or not the different states of the wayfinding cognitive process, explained in the first section.

2.6 Comparison of Current Navigation Aid Systems

The identification of these states remains a key challenge, as it is the case for all context-aware systems [27, 102].

- **Targeted users:** it describes for whom the system was designed, for people with disabilities as an example.

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Ref.	Name of the system	Pedestrian Navigation Mode	Navigation	Interaction Support	Landmarks Suggestion	Context: Wayfinding task Awareness	Targeted users
[43]	NA	Yes	Outdoor	Phone	Yes	No (just path following)	No specific users
[65]	NA	No (Segway)	Outdoor	Smartphone, Augmented Reality (AR)-Vibrotactile	No	No (just path following)	No specific users
[87, 86]	MapLens	Yes	Outdoor	Phone, Augmented paper map	No	No (just path following)	No specific users
[31]	CabBoots	Yes	Outdoor	Vibrotactile on shoes	No	No (just path following)	No specific users
[95]	Tactile Wayfinder	Yes	Outdoor	Vibrotactile	No	No (just path following)	No specific users
[46]	NA	Yes	Outdoor	AR-based, Voice-based and Digital Map-based (three applications were installed on a Smartphone)	Yes	No (just path following)	No specific users
[115]	NA	Yes	Outdoor	3D panorama view on Smartphone	Yes	No (just path following)	No specific users
[113]	Pharos	Yes	Outdoor	Smartwatch	Yes	No (just path following)	No specific users

2.6 Comparison of Current Navigation Aid Systems

Ref.	Name of the system	Pedestrian Navigation Mode	Navigation	Interaction Support	Landmarks Suggestion	Context: Wayfinding task Awareness	Targeted users
[83, 84]	NA	Yes	Outdoor	AR glasses vs Spatialized sounds with a bone conduction headset vs Smart-watch	No	No (just path following)	Older pedestrians
[71]	Audio Bubbles	Yes	Outdoor	Audio	Yes	No (just path following)	No specific users
[21]	NA	Yes	Outdoor	3D-Maps on Smartphone	Yes	No (just path following)	No specific users
[111]	NA	Yes	Outdoor	AR on Smartphone	No	No (just path following)	No specific users
[72]	NA	Yes	Outdoor	Vibrotactile feedback on feet	No	No (just path following)	No specific users
[110]	NA	Yes	Outdoor	Vibrotactile-foot feedback connected to a smartphone	No	No (just path following)	Blind pedestrians
[12, 101]	Shoe me the Way	Yes	Outdoor	Vibrotactile feedback on shoes	No	No (just path following)	No specific users
[18]	Guiding Light	Yes	Indoor	AR using light projector	No	No (just path following)	No specific users

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Ref.	Name of the system	Pedestrian Navigation Mode	Navigation	Interaction Support	Landmarks Suggestion	Context: Wayfinding task Awareness	Targeted users
[47]	NA	Yes	Outdoor	Nonspeech audio (earcons, spearcons and short pulses)	No	No (just path following)	No specific users
[7]	NA	Yes	Outdoor	Music listening with spatial audio for route and beacon guidance ² using headphones	No	No (just path following) outcomes: beacon guidance is better for familiar surroundings and route guidance for unfamiliar areas	No specific users
[98, 97]	NA	Yes	Outdoor	AR vs Voice vs Digital map (using smartphone)	No (highlighting few landmarks on the digital map without using them into guidance instructions)	No (just path following)	No specific users

²Beacon guidance: navigation aid method, different from turn-by-turn instructions, aims to inform the user about the direction of the destination [7]

2.6 Comparison of Current Navigation Aid Systems

Ref.	Name of the system	Pedestrian Navigation Mode	Navigation	Interaction Support	Landmarks Suggestion	Context: Wayfinding task Awareness	Targeted users
[112]	NA	Yes	Outdoor	AR on Smartphone, Digital map, Compass, Radio	No	No (just path following)	No specific users
[51]	NA	Yes (including public transport)	Outdoor	AR vs Digital map on smartphone	No (they were displaying points of interest)	No (just path following)	No specific users
[55]	NA	Yes	Outdoor	AR vs Digital maps on smartphone	Yes	No (just path following)	Forced migrants (no specific needs)
	Adapted NAS - Approach proposed in this thesis	Yes	Outdoor	AR Glasses, Smartphone, headphones, haptic feedback	Yes	Yes	People with ID

Table 2.1 Comparative table of navigation aid systems

Wayfinding & Navigation Aid Systems (NAS) for pedestrians in Urban Mobility

According to Table 2.1, 22 related work were compared. Different systems were designed for outdoor navigation for pedestrians. All of them, except [55, 110], were targeting users without specific needs. Seven papers [21, 43, 46, 55, 71, 113, 115] considered including landmarks into the guidance information displayed for users. Nine of these studies considered the use of AR basing on the benefit of being able to receive the navigation guidance without altering the users' focus on their environment. To summarize, no work has included the wayfinding process into the design of their navigation aid systems. We argue that the Path Following state was the only one targeted without considering different states where the user may feel less supported and less understood.

2.7 Navigation for pedestrians with ID in Urban Mobility

Mobility, i.e. the ability to travel through the environment, is an essential skill for social participation. Knowing how to navigate the environment allows us to get to school or work, visit our families and friends, have leisure activities, etc.

Spatial navigation refers to the ability of moving from point A to point B [36] and involves three types of knowledge: landmarks, paths and survey (cognitive map of the environment) [103]. This knowledge is acquired during childhood through different navigation experiences [77]. Some people may have difficulties in acquiring this knowledge and thus in moving autonomously. This is the case for people with intellectual disabilities (ID).

According to the Diagnostic and Statistical manual of Mental Disorders (DSM)-5th edition [104], ID is a neurodevelopmental disorder that is manifested by intellectual and adaptive deficits in several areas: conceptual, social and practical. The diagnosis of ID can be made if a person presents with both: (1) a deficit in intellectual functions (in the areas of reasoning, problem solving, planning, abstraction, judgment, academic learning and experiential learning), confirmed by clinical assessment and standardized individual intelligence tests (criterion A) and (2) a deficit in adaptive functions limiting functioning in one or more fields of activity of daily life (communication, social participation, independence) in various environments such as home, school, work or the local community (criterion B). Finally, the onset of intellectual and adaptive deficits occurs during the developmental period (criterion C).

Field studies conducted on the travel habits of ID persons unanimously show a strong restriction on travel, which is limited to routine journeys made in the neighbourhood of the home and the frequented institutions; such restrictions reduce the opportunities for social participation of these individuals [75, 6].

2.8 Ontology and Navigation for people with ID

On the other hand, aging with ID can be more challenging comparing to the general population. People with ID may have unidentified and unmet needs by healthcare facilities since there is a good evidence to experience the same age-related chronic diseases as the general population [94, 96]. Persons aging with ID experience unrecognized or poorly managed health conditions (e.g. visual and hearing impairments, mental health problems) and higher rates of morbidity and mortality than the general population [94].

Aging with ID can be complex, as the aging process varies depending on the underlying condition. Adults with Down syndrome, for example, experience accelerated aging including a genetically elevated risk of developing Alzheimer disease. The diagnosis and management of Alzheimer disease in persons with Down syndrome is further complicated by increased risk of hypothyroidism and depression [96].

In recent decades, concerning navigation, research work in human spatial cognition has led to a better understanding of environmental learning. Such work has produced various models of reasoning and spatial behaviour and ultimately led to the development of navigation aid systems available on smartphone. Despite being easy to use and efficient (from a technical point of view), these tools do not always seem to be adapted to the specifications of users, particularly people with ID [38]. Indeed, recent work on the spatial navigation of people with ID shows that, during their travels, people with ID are able to acquire knowledge of landmarks, i.e. select and memorize objects and places present in the environment [23]. However, the landmarks chosen are not always effective for decision-making. Indeed, some studies show that ID individuals may lack selectivity in their choice of landmarks (non-unique objects (e.g., traffic lights, street furniture), mobile objects (e.g., vehicles)) even if they are located at intersections [23]. This lack of selectivity leads to navigational errors. The acquisition of route knowledge is also present for people with ID, but after a longer learning period than for typically developing individuals [23, 76, 74, 60, 63, 109, 80]. On the other hand, survey knowledge allowing more flexible mobility is more rarely acquired [77, 60].

Given these particularities in learning and navigating within an environment, our goal is to develop a mobility assistance system for people with ID. Indeed, because of their difficulties in moving around, these people need systems adapted to their needs but also to their cognitive functioning. It is within this context that an ontology has been developed to provide a common language and basic knowledge of spatial navigation.

2.8 Ontology and Navigation for people with ID

According to Noy [88], an ontology is a description of the concepts of a domain (classes), of the properties of each concept describing the different characteristics and attributes

Wayfinding & Navigation Aid Systems (NAS) for pedestrians in Urban Mobility

of the concept (slots), and of the limits of the slots (facets). The ontology provides a basis for information exchange and collaboration, but also the vocabulary of an application domain [106].

Many ontologies have already been developed in the field of space navigation and transport use. The work of Kettunen and Sarjakoski [54] presents the construction of an ontology of landmarks for spatial navigation in a natural space. These researchers conducted a series of studies with 42 participants in order to collect the landmarks used by people when travelling in the natural environment and in various situations (summer, winter, day and night). The obtained landmarks helped with the creation of an ontology that is intended to be used to develop customizable navigation systems that can be used for travel in the natural environment.

In the same field, other researchers [89] have defined five ontologies as part of a project to develop a new model for displaying information for hikers and tourists. In their paper, they present more specifically two ontologies (walk and navigation) that are then used by the system to provide textual instructions and navigation directions in different languages.

Other works focus on urban mobility and, in particular, on transport use. For example, Timpf [106] compares two wayfinding ontologies involving several modes of transport in urban environment. Wayfinding consists of a planned trip to a destination that requires the establishment of a route [81]. The specificity of this work is adopting an uncommon point of view in the work on ontologies and wayfinding, the one of the person who is travelling. Thus, this author has developed not only an ontology of wayfinding from the perspective of the transport system but also an ontology of wayfinding from the perspective of the person who uses transport. By comparing the two ontologies obtained, Timpf shows that they overlap on some concepts (like transportation infrastructure, signage, direction, time, and economy) but not on all of them such as: moving. Therefore, the ontology from the traveller's point of view is not a subset of the ontology from the transport system's point of view.

In the same field of application, Mnasser and her collaborators [45] present a public transport ontology that considers several concepts in connection with a journey planning that is as best and most relevant as possible for the user. The objective of this work is to be able to use this ontology to help the user to choose the best route to get from one place to another.

Finally, an ontology can also be used to provide the public transport user with personalized information. For example, De Oliveira and her collaborators [25] published an article on the use of a transport ontology (metro, tram, train and bus) to customise the content of user interfaces.

To the best knowledge of the authors of this manuscript, there is no work that has used an ontology in the field of ID and mobility. The aim of this work is to propose a navigational aid

system adapted to people with ID to facilitate their autonomous mobility. For this purpose, an ontology was developed in the field of spatial navigation that serves as a basic model for the development of adapted navigation systems (cf. Chapter 3).

2.9 Conclusion

This chapter illustrated in a more elaborated way the construction of spatial knowledge and how current NAS are supporting people's navigation in a way that disconnect them from real world. This causes less spatial awareness and leading to certain dependency which is created due to the repeated exposure to this "blinded navigation". As a result and despite the unquestionable benefits of NAS, navigation skills will decrease and be replaced, to a certain level, progressively by escaping to easier options such as following guidance instructions.

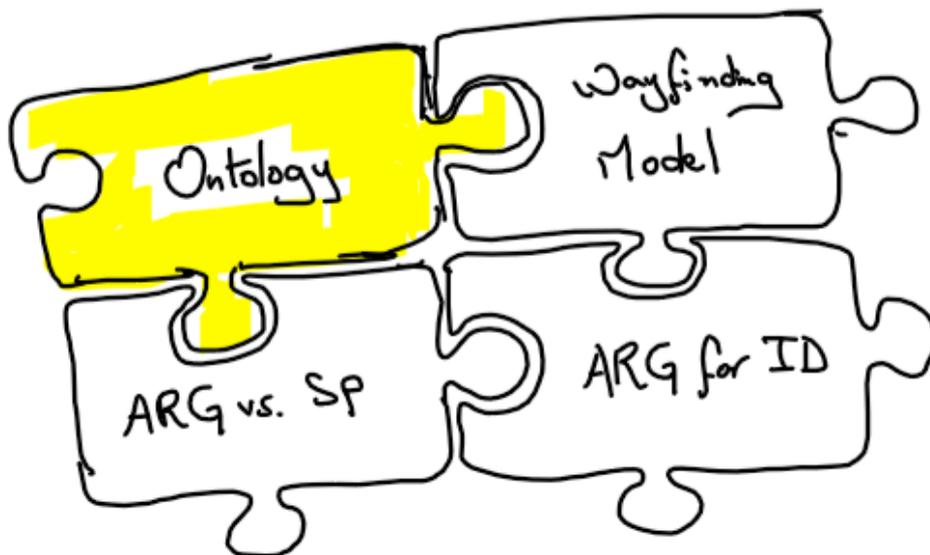
When it comes to people with ID, the current NAS are still far from being fully adapted and functional in different situations. For instance, unexpected changes in public transport schedule or bus stops location would affect drastically the performance of people with ID and most adapted NAS does not provide sufficient assistance in these circumstances. The goal of this thesis is to address these questions from different scientific perspectives: wayfinding process, common language tool about spatial navigation (the novel ontology presented in the next chapter), understanding the influence of the device and including landmarks on navigation performance and finally co-designing an adapted NAS that would help people with ID during their daily navigation.

Part II

Contributions

Chapter 3

Ontology for Spatial Navigation



ARG: Augmented Reality Glasses
SP: Smartphone

3.1 Introduction

Spatial navigation is a complex task even if it seems subconscious and sometimes automatic for most of people who are familiar with their environment. As explained in Chapter 2, it is divided into two components (wayfinding and locomotion) [114]. Each component interacts with the environment in a different way: when considering the first component, the locomotion, more considerations are given to accessibility level of a sidewalk or a road for example. When considering the cognitive component, the wayfinding, the focus is given to path details as landmarks and salient elements of the surroundings. The reader of this thesis may notice that spatial navigation covers a bunch of concepts related to the navigation itself, and to the environment including the road infrastructure and transport modes, etc. Thus, the main goal of this chapter is to put the light on **Spatial Navigation** concepts through a novel ontology including concepts definition and their categories. This ontology was created in the first place to offer a common ground, at a communication level, between different stakeholders of ValMobile project (researchers in human-computer interaction, psychology, ergonomics, disability and human automation; qualified trainer for people with ID). This novel ontology will be involved implicitly in the next chapters as a basis for defining the used language for each situation and will serve as a support for navigation aid system design. Another interesting use of this ontology is discussed in the perspectives section considering the design of an adaptive NAS. In this chapter, the approach used to create the ontology is presented with the obtained results. A first based-scenario validation is illustrated at the end in order to showcase the strength and highlight the limitations of this first ontology. This ontology was a subject of two published papers (cf. [61, 62])

3.2 Approach used to generate the ontology

As mentioned in the introduction, this ontology consists of defining most of the related concepts to **Spatial Navigation** domain. This first product was carried out in collaboration with researchers in psychology, specialized in ID people mobility; and computer science, specialized in Human-Computer Interaction, mobility and transport domain. A total of eight working meetings took place over a three-month period to define the approach, generate the concepts cloud, different categories and the definitions. Several methods for establishing an ontology are present in the literature [88, 40]. They generally follow these common steps: definition of the purpose of the ontology, conceptualization, formalization and validation (cf. Figure 3.1).

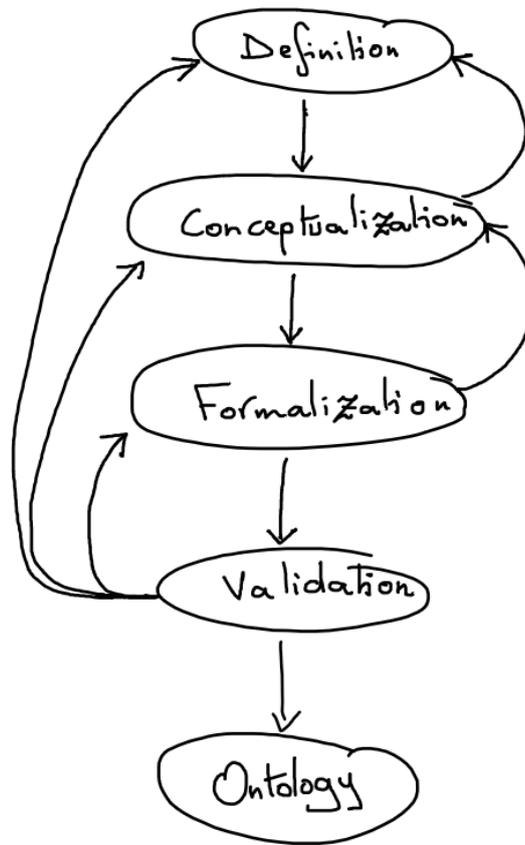


Fig. 3.1 Main steps followed to create this novel ontology (inspired from [88, 40])

3.2.1 Definition

This ontology is created to serve as a knowledge basis for the project research team in order to smooth the communication between different stakeholders. Designing a NAS for people with ID represents a challenge and it requires teaming-up efforts of a multidisciplinary collaborators. The presented ontology intends to cover the concepts related to spatial navigation field without considering the intellectual disability.

3.2.2 Conceptualization

This ontology design stage represents the main phase where different concepts are gathered, categorised and defined. In order to carry out this conceptualization stage, the spatial navigation definition, introduced in Chapter 2, was used as a first word generator. After gathering these first concepts, the list was extended using a brainstorming method. This helped to create a representation similar to a word cloud illustrated by Figure 3.2.

3.2 Approach used to generate the ontology

After obtaining this word cloud, different concepts were gathered together under more general concepts on different levels to reach the main concept of "spatial navigation". Finally, each concept was defined in regard to its parent (direct-general concept) and its children (direct-specialised concepts). This definition step was based on using some references as Larousse dictionary [Lar], the Transmodel model [Tra], the National Centre of Textual and Lexical Resources (in French: Centre National de Ressources Textuelles et Lexicales) (CNRTL) [Cen] and the Techno-Science glossary [Tec].

3.2.3 Formalization

This step consists simply on translating the concepts hierarchy already defined into a standardized format for the ontology. The language used for this translation is called OWL, which stands for Web Ontology Language, along with the software Protégé¹. Figure 3.3 shows the ontology hierarchy in Protégé.

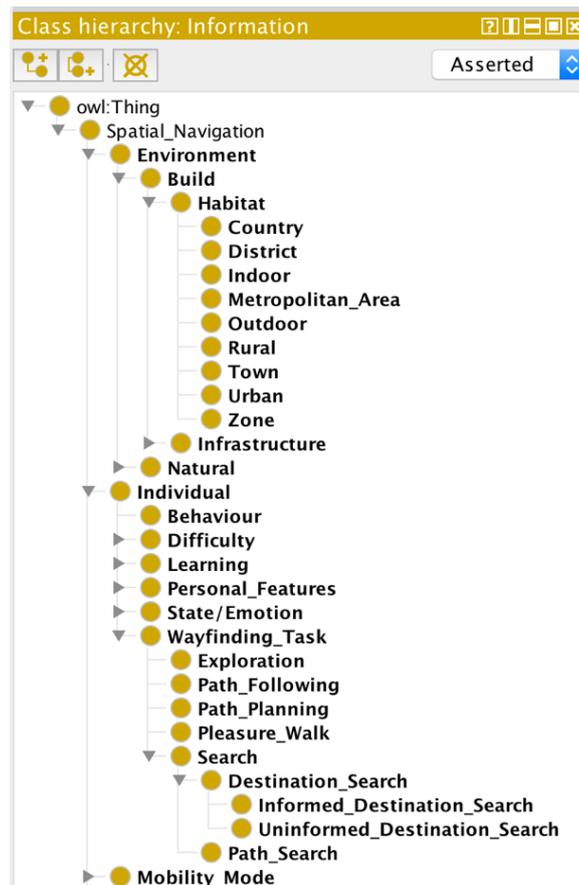


Fig. 3.3 Extract of the ontology in Protégé [61]

¹<https://protege.stanford.edu/>

The final step of validation is presented in Section 3.4.

3.3 Overview of the obtained ontology

The produced ontology contains 201 defined concepts (in French). The central one is "Spatial Navigation" defined as "a coordinated and goal-directed self-movement through the environment that can be broken down into two sub-components: locomotion and wayfinding" [81]. This concept can be decomposed into four classes: Mobility mode, Environment, Information and Person (cf. Figure 3.4; to consult the entire ontology, please refer to Appendix A).

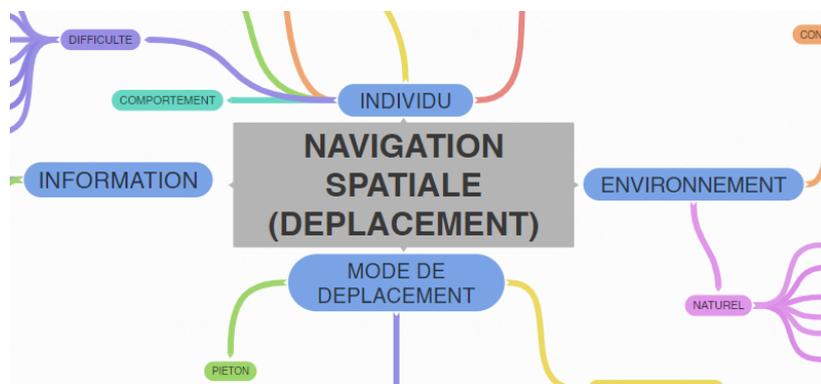


Fig. 3.4 Extract of the ontology presenting the first level of sub-concepts.

3.3.1 Presenting a selected sub-concept: "Wayfinding task"

In order to explain the details of this ontology, the sub-concept *Wayfinding task* of *Person* was selected. This sub-concept represents the cognitive part of the navigation process. Figure 3.5 illustrates the concepts-tree under the wayfinding task.

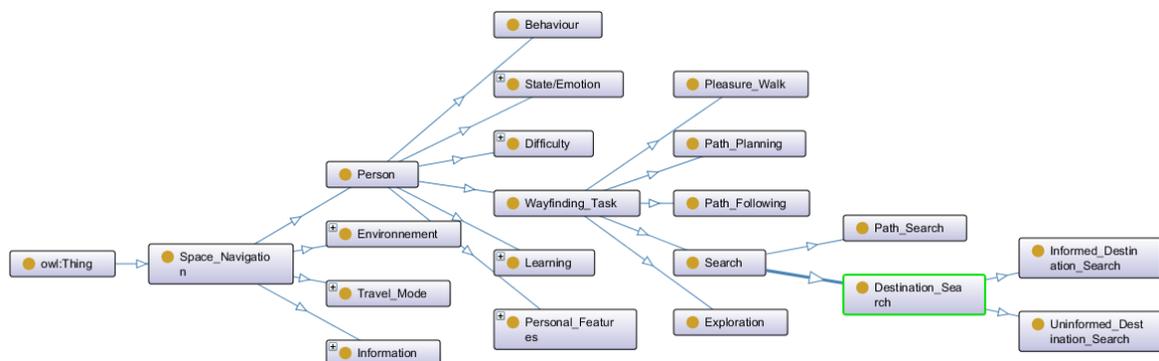


Fig. 3.5 Extract of the ontology presenting the sub-class "Wayfinding tasks" [61]

3.3.2 Definitions given to the sub-concepts of "Wayfinding task"

The elements constituting this subclass correspond to the wayfinding tasks defined by Wiener and his collaborators [114] in a taxonomy based on the level of involved spatial knowledge (landmarks, routes, survey) (cf. Chapter 2).

Seven wayfinding tasks are distinguished (they are represented in a tree structure in Figure 3.5): (1) exploration, (2) pleasure walk, (3) path following, (4) path planning. When it comes to search, two tasks are distinguished: (5) path search, and destination search. The last one is divided into: (6) uninformed destination search and (7) informed destination search. Definition of each element is presented in the Table 3.1 below.

Concepts	Definitions
(1) Exploration	Travelling without a specific destination (without an established goal) in an unknown environment
(2) Pleasure Walk	Travelling without a specific destination (without an established goal) in a known environment
(3) Path Following	Travel with a specific destination knowing its location in a known environment using a known route
(4) Path Planning	Travel requiring the identification of the steps to be taken to get to a specific destination with a known location in a known environment.
Search	Travel with specific destination
(5) Path Search	Travel requiring the development of a route to a specific destination in an unknown environment
Destination search	Travel with a specific destination whose location is unknown
(6) Uninformed Destination Search	Travel with a specific destination with unknown location in an unknown environment
(7) Informed Destination Search	Travel with a specific destination whose location is unknown in a known environment

Table 3.1 Definition of the sub-class « Wayfinding tasks » concepts [61]

3.4 Scenario-based validation of the ontology

The goal of this section is to present a first validation based on a real life scenario in an urban environment [61]. For this purpose, a persona was designed in order to create a representation of potential users. Then, the travel scenario including the path followed during the navigation is presented. At the end, a scenario describes an imagined NAS used to accomplish the requested task by offering navigation guidance for the selected person.

3.4.1 Persona designed

A persona has been designed to represent a group of users with an intellectual disability. This persona allows the representation of a target group through a fictitious person with social and psychological attributes and characteristics. This marketing concept has been taken up by the community in the field of HCI, in particular by Alan Cooper [20]. The expression of needs involves the creation of scenarios in the form of use cases corresponding to the tasks to be carried out through the components of the user interface [22, 48]. This scenario creation, in this case, is based on the persona visible in Figure 3.6.

Nabila

- General Profile:
 - Age: 20 years old
 - Address: Valenciennes, France
 - Status: Enrolled in a medical-professional institute (professional training institution for adolescents with intellectual disabilities)
- Professional Goals:
 - To be hired in a sorting and packaging workshop
- Knowledge & experiences:
 - Familiar with the use of communication technologies and social media networks on her smartphone
- Specific needs:
 - Mild level of intellectual disability which requires a minimum assistance
 - Difficulty to understand quickly numerous and complex information
 - Difficulty to establish and maintain a communication
 - Difficulty orienting herself and finding her way in space



Fig. 3.6 Nabila, the persona used for this validation study [61]

3.4.2 Validation scenario

The scenario designed for this validation is as follows: Nabila, our persona, has to travel in the agglomeration of Valenciennes, in France, and since she has orientation difficulties (cf. Figure 3.6), she will seek the help of a navigation assistance system. To sum it up, she plans to attend a cinema projection, during the day, using her digital assistant. The itinerary associated with the scenario is presented in Figure 3.7. This assistant has been imagined considering the four main concepts (environment, information, individual and mode of travel) from the ontology presented earlier in this chapter.

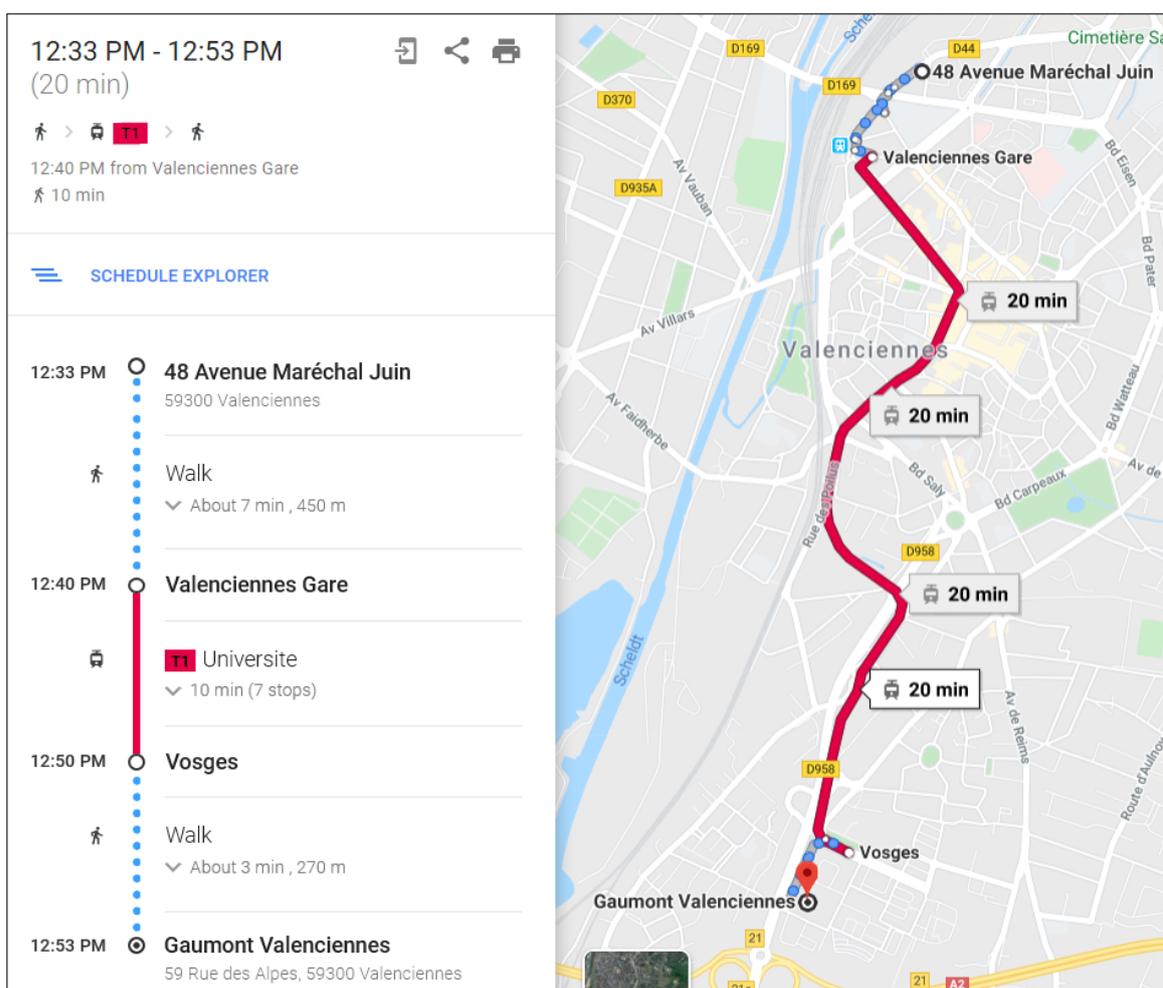


Fig. 3.7 Map of the trip showing different steps [61]

3.4.3 Description of the imagined NAS based on the suggested scenario

This imagined system takes into account a set of adaptation rules that allows the association of a context with a specific behaviour of the application. The context of navigation is based on the description provided with the scenario, for example the nature of a street (quiet or busy), the travel mode (pedestrian, public transport, etc.). This scenario, taken into account for the application design, is the following:

« Nabila would like to attend a film session in the early afternoon. She consults, at home, the website of the cinema to see the available films for today. She wants to see a film for which there is a screening at 2:10 pm. She wishes to arrive an hour in advance and have lunch on site before the film. So, she makes an itinerary on her laptop with Google Maps. She sees that she is on time. She gets ready and tells her mobility assistant [58] that she wants to go to the Gaumont cinema. Nabila is not yet familiar with the city and has never gone for a walk in the direction of the train station. The assistant therefore takes this information into account in the context. »

The scenario for using the digital assistant is detailed in Figure 3.8 and Table 3.2.

The path is composed of four parts:

- **Indoor:** which includes interactions with the digital assistant before leaving the house.
- **Street 1:** corresponding to the journey made in the street to the tramway station.
- **Tramway:** corresponding to the journey made inside the tramway.
- **Street 2:** corresponds to the journey made in the street to the cinema.

The travel times of the different sections on the Google Maps route have been plotted on the Gantt chart. These sections 2, 3 and 4 have the following travel times: 7 min, 10 min and 3 min respectively.

3.4 Scenario-based validation of the ontology

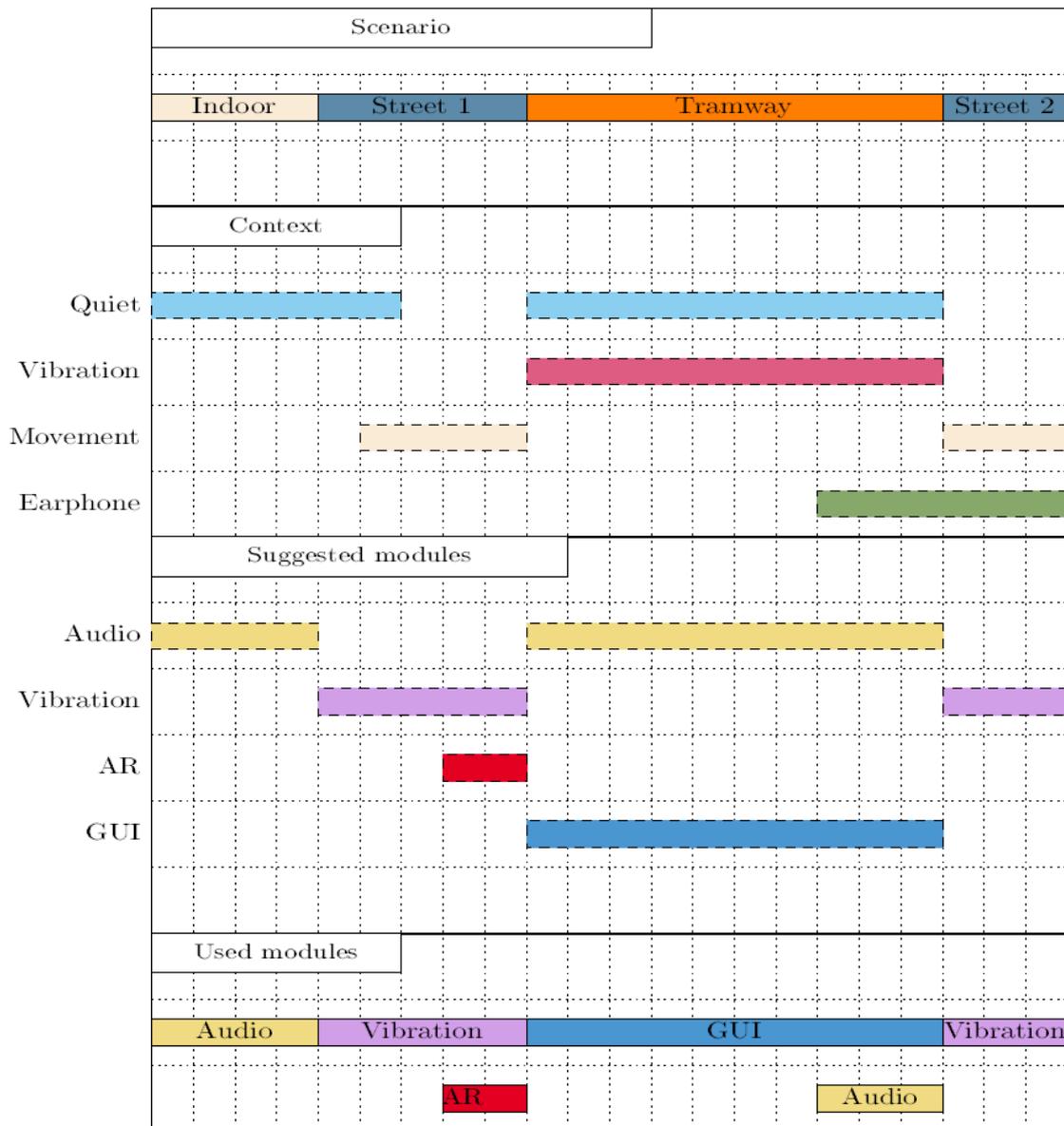


Fig. 3.8 Gantt chart associated to the scenario illustrating the different steps, the context and the outcome of the adaptation [61] (AR: Augmented Reality; GUI: Graphic User Interface)

Figure 3.8 is divided into 4 parts. The first one (top) provides a decomposition of the scenario with the succession of the types of places travelled (Indoor, road section, tramway station). For each of these types of places, the context is modified. For instance, the indoor environment has the characteristic of being quiet, whereas when travelling along Street 1, the user is considered to be constantly on movement. These different elements of context are

Ontology for Spatial Navigation

provided as input to the adaptation engine ² present in the navigation assistance. The rules of this engine make it possible, according to each context, to provide a set of adapted support modules (illustrated in the part of Suggested Modules). The modules actually used during this scenario are then visible in the lower part of the same figure (Used modules).

Table 3.2 explains the sequence of the adaptation mechanism according to the different elements of the context. This table presents the different steps of the scenario numbered from 1 to 12. For each step, the columns « Context » and « Wayfinding » provide the characteristics of the environment and the state of the wayfinding task respectively (cf. Figure 3.4).

Scenario	Context	Wayfinding
1 - Nabila plans to go alone to the cinema	She is alone. She is at home	"Directed"
2 - She selects the destination on her digital assistant	She is alone. She is at home	"Destination location search"/"uninformed search"
3 - The audio module allows her to find the right orientation after leaving her home (for example, towards the pharmacy)	The environment is quiet. Nabila did not plug in her earphones.	"Target approximation" /"Path following"
4 - Nabila walks towards the tramway station «Gare» using the «Vibration» module	The environment is quiet. She is walking on the street (dangerous). Nabila does not like to disturb her surrounding	Idem
5 - She approaches the station, the module «Vibratio » still works. The module AR completes her knowledge of the environment by indicating the station location	Nabila has almost stopped. The environment is noisy	Idem
6 - Nabila arrives at the tramway station. She receives information about the next departure time using AR	Idem	Idem

²Disclaimer: adaptation mechanisms were not addressed in this thesis. It was explored and mentioned in this chapter to give a comprehensive overview of potential system design. This aspect is discussed more in details in the perspectives at the end of this manuscript.

3.4 Scenario-based validation of the ontology

7 - She gets on the tramway. The assistance recommends the Audio module. As a second option, the assistant suggests the GUI module that Nabila selects	The environment is quiet. Nabila does not have her earphones. Nabila does not like to disturb her surrounding. There are a lot of vibrations in her environment.	Idem
8 - GUI module provides information about the stations. The system also asks Nabila to memorise the description of the remaining path after getting out of the tramway		Idem
9 - Nabila plugs in her earphones, the audio module is launched. The GUI module remains active. Nabila listens to the relevant information (learning remaining path, next station, etc.). Then she hears that she must get off at the next station.	Nabila has just found her earphones	Idem
10 - She gets off the tramway. She arrives near the destination. She still has to go 270 m	The environment is noisy. She is walking on the street (dangerous)	Idem
11 - During the remaining trip, the system provides directions using the module «Vibration» . Nabila should have memorised landmarks to facilitate her trip	Idem	Idem
12 - Nabila arrived to her destination		

Table 3.2 Table detailing the presented scenario with a Gantt chart.

At the end of this validation process, the ontology presented shows its ability to cover the different concepts involved within the spatial navigation. Indeed, the different elements of urban environment such as street or tramway station appear under the concept « Environment

» containing, among other sub-concepts: « habitat », « road », « roadway », « station », etc. (cf. Figure 3.3).

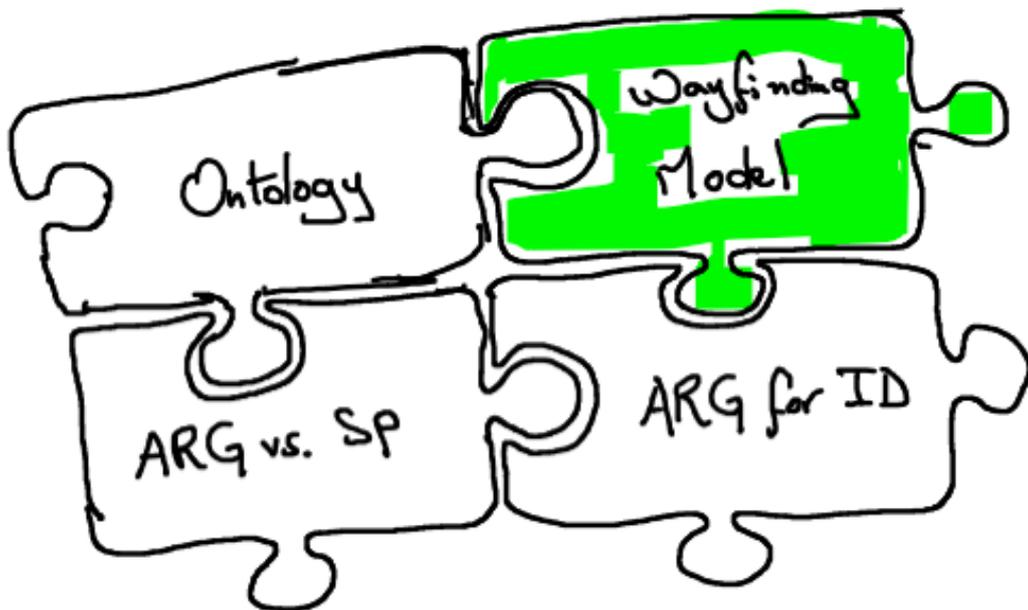
3.5 Conclusion

This chapter introduced a novel ontology of spatial navigation concept. This ontology helped to build a common communication language between different team members. It covered multiple concepts related to spatial navigation: person, environment, travel mode and information. In order to create this ontology, the process followed covered mainly four steps: definition, conceptualization, formalization and validation. Couple of meetings were required to achieve the obtained result. The final step was the validation which represents an important section of this chapter. This step included a detailed description of the scenario used and the NAS imagined according to the same scenario. This final step gave a first validation by showing that a NAS could be designed including the defined concepts provided by the ontology. Furthermore, it showed how this novel ontology could cover main concepts related to the spatial navigation. Perspectives on using this ontology are given in the general conclusion.

The next chapter will introduce the new wayfinding model that has been mentioned earlier in this chapter. This wayfinding model will help to structure the information gathered about the environment and the cognitive tasks of the traveler.

Chapter 4

Using Wayfinding Model to Design Next Generation of NAS



4.1 Introduction

People may encounter different challenges while performing pedestrian navigation tasks. The complexity of these challenges could differ according to someone's physical and cognitive abilities. For instance, the wayfinding taxonomy (cf. State of Art: Chapter 2) and the ontology for spatial navigation (cf. Chapter 3) [62] illustrated how the navigation could be complex and that people needs may evolve in contrast with their surroundings. By considering the cognitive part of the navigation, wayfinding, NAS could offer a better, adapted and seamless assistance for people to connect and learn more about their surroundings.

This chapter proposes a design-oriented approach using the novel **Wayfinding Model** (cf. Figure 4.1 which has been published in [58, 59]). This ready-to-use design tool may help in exploring different states of the cognitive process of the navigation task. This model highlights different transitions between these states which may serve as a trigger for NAS adaptation; further details are presented later in the next sections. This chapter allows to present the wayfinding model and how it could be used to design adaptive NAS to offer a tailored assistance to the needs of the users. In the current work and in order to dive deep into the design details, one central state would be considered which is "*Path Following*". A system design is also suggested based on the proposed model, with a preliminary study that aimed to test this "*Path Following*" state. This chapter concludes with design guidelines that could be considered while designing NAS in general and more specifically for people with ID.

4.2 Proposal: Wayfinding Model as design model

The proposed Wayfinding Model, illustrated with a UML state diagram, allows to highlight different states of this cognitive process. This diagram shows how a person (also called navigator below) can change the task of the navigation according to the spatial knowledge they have. The main goal of this diagram is to explicit the transitions between different states. Thus, this model aims to help with creating adaptive navigation systems that may assist the user for all the states of the wayfinding. It is why the proposed model can be considered as a design model.

According to the Wayfinding taxonomy [114], the wayfinding state depends on three variables representing the user's spatial knowledge. Those variables, notated as a triple, consider the knowledge about: (a) destination location, (b) path towards the destination and (c) the survey understanding of the environment (for simplicity reasons, knowledge of the environment will be used to the survey knowledge in the rest of this chapter). A

4.2 Proposal: Wayfinding Model as design model

representation is used to express the knowledge level: "+" available, "-" unavailable, and "?" undefined. For instance, this combination {?,?,?} (*Undirected state*) means that the system does not know, at a specific moment, if the user knows or not the destination, the path and the environment. This second combination {+,-,+} (*Path planning state*) means that the system is aware that the user knows the destination and the environment but not the path guiding to the destination.

Three sub-processes can be mainly identified based on wayfinding states:

- **Undirected wayfinding:** the navigator does not have a specific destination to reach. According to the third knowledge attribute of the environment, this navigator could move from (a) *exploration* to (b) *pleasure walk* and vice versa depending on their knowledge of the environment. Specifically, if the individual does not know the environment in which they find themselves, they are in a state of exploration. The objective is then to become familiar with the environment by observing the surroundings. For example, if someone goes to a conference in an unfamiliar city, when they arrive to the hotel, they will walk around to observe and learn more about their environment (subway station, restaurant, etc.). They do not walk with a goal to reach. This knowledge will be useful if they decide to reach a specific place (directed wayfinding situation). Conversely, when an individual knows the environment and decides to walk without a specific destination, they are in a *pleasure walk* situation. They may gain better bearings thanks to the acquired knowledge.
- **Destination locating:** it is when the navigator decides to reach a specific destination with an unknown location. The goal of this sub-process is to locate this destination using a (c) *uninformed* or (d) *informed search* which depends on the navigator's knowledge of the environment. For example: "A friend recommends a restaurant (specific destination). Then, they will be asked for its location (*location search*) and they clarify that it is located next to the main post office at the city centre". The location is well located thanks to the landmark provided.
- **Path Planning & Following:** assuming the destination is already located, the navigator proceeds to think progressively of a path. When this second attribute is known, they follow the defined path to approach their destination ((g) *path following*). Getting back to the previous example: the landmark provided may recall, from the spatial memory, a known path if the area is familiar ((f) *path planning*) or in the other case, it will invite to search for a path using a NAS ((e) *path search*).

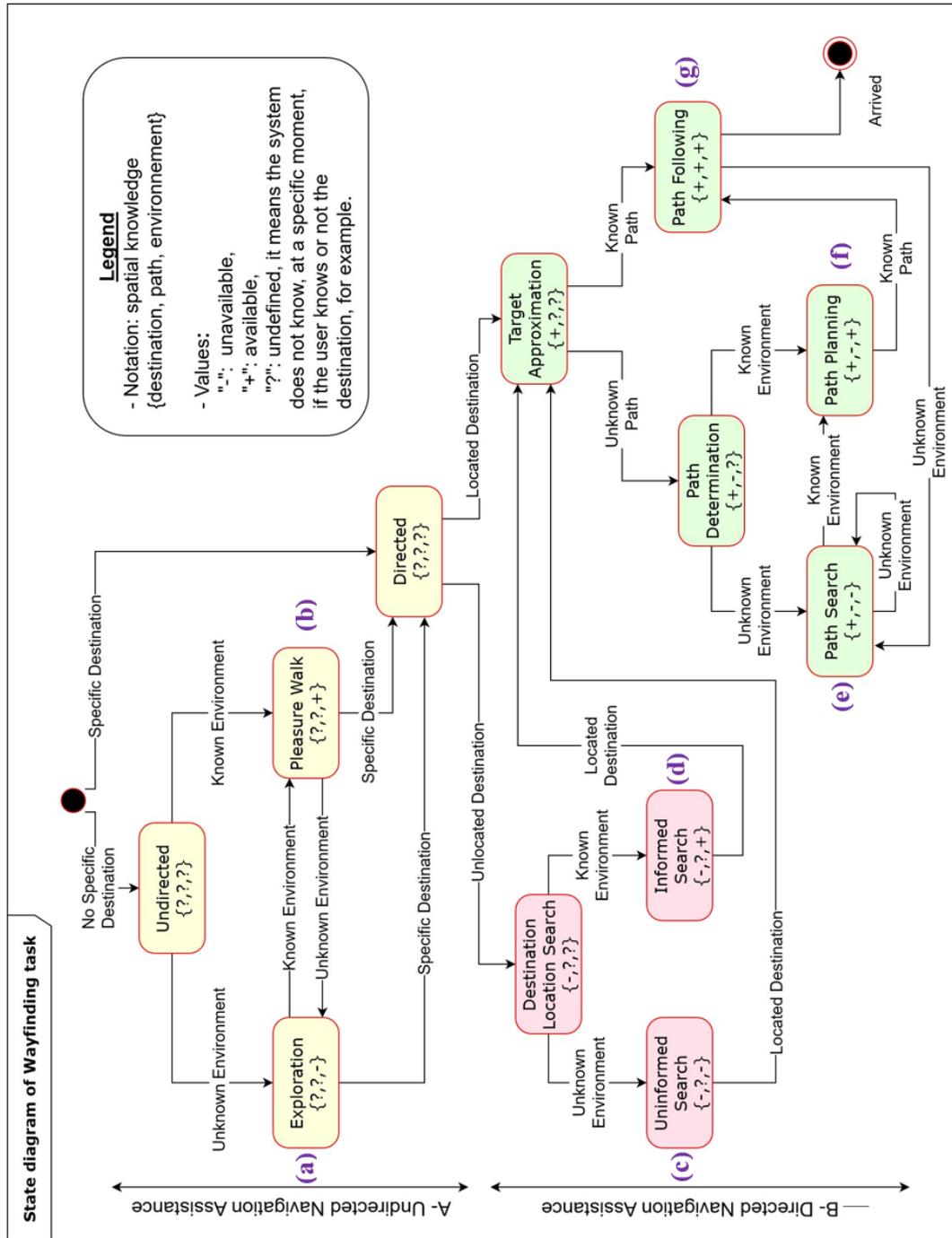


Fig. 4.1 Wayfinding Model illustrated using a state diagram.

4.3 How to improve NAS considering the wayfinding state awareness

The next UI sketches propose how a navigation assistance should be designed considering the wayfinding state awareness. The user interfaces being considered are displayed on AR glasses and Smartphone for digital maps. This choice is based on the fact that smartphones are obviously the most used platform for pedestrian navigation. When it comes to AR glasses, this platform is considered, in the course of this thesis, as a potential improvement to current NAS. Other platforms of interaction (as smartwatches, vibrotactile belts, headphones, etc.) could be considered as a perspective for the current work and based on its findings.

4.3.1 Undirected wayfinding assistance

The goal of this assistance mainly is to give an augmented informative layer of current environment. This may contribute to enrich the users cognitive map. According to the users' mobility history, some relevant landmarks could be identified and then recommended. For instance, Figure 4.2 represents a sketch of augmented reality glasses highlighting a pharmacy as a landmark. This assistance may help with spatial knowledge acquisition and provide more engagement with the surroundings [103, 50, 81].

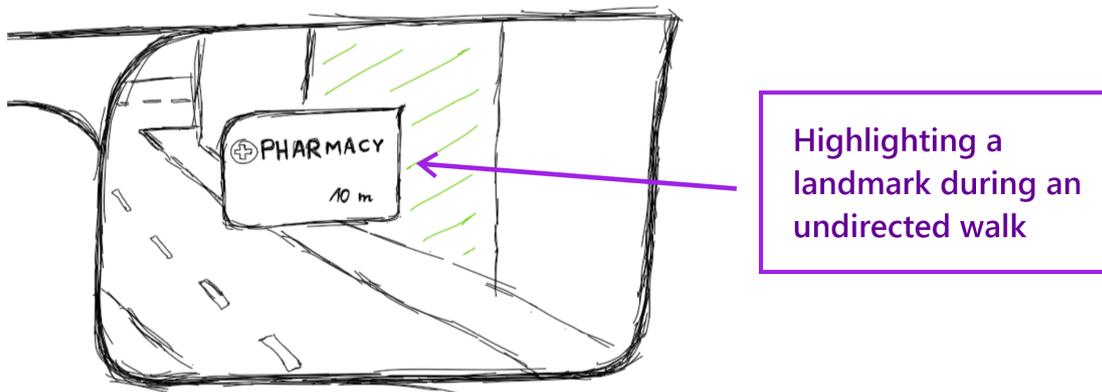


Fig. 4.2 Undirected Wayfinding Assistance - AR Glasses [59]

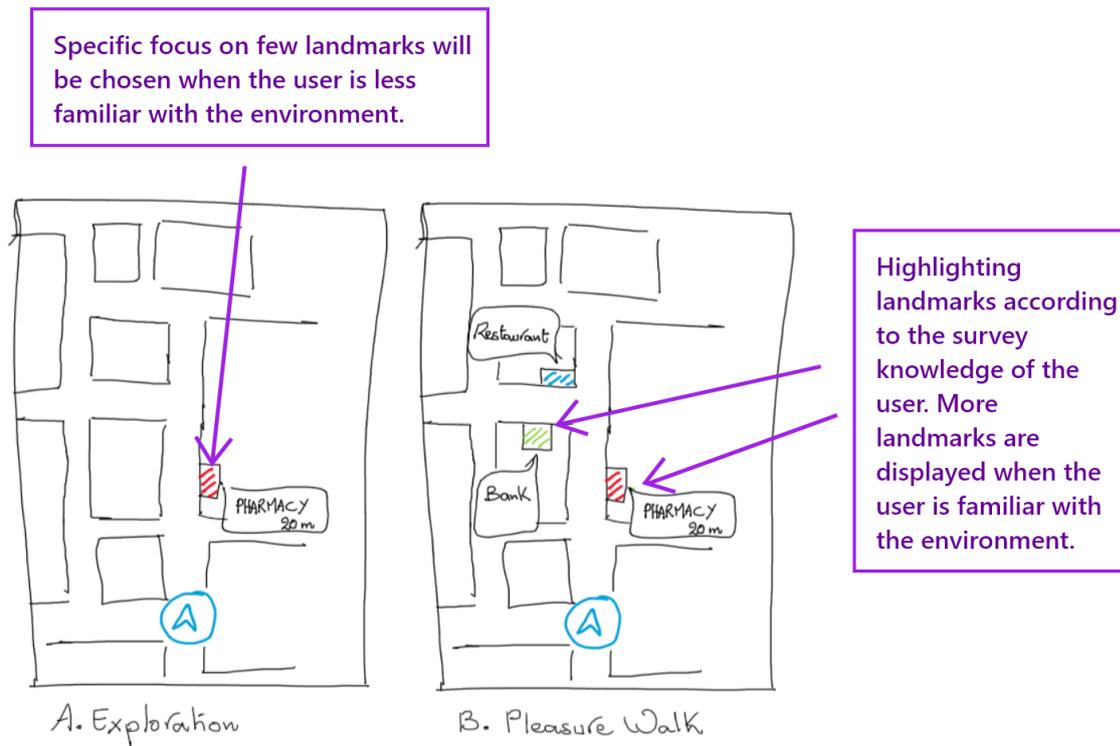


Fig. 4.3 Undirected Wayfinding Assistance - Mobile Application [59]

Figure 4.3 shows an adapted assistance based on the wayfinding state. When the users are in unknown environment (*Exploration*: state (a) in Figure 4.1), the assistance could provide the users with focused landmark recommendations. Otherwise, when the environment is known (*Pleasure Walk*: state (b) in Figure 4.1), the assistance could suggest fewer landmarks. In the second case, the aim of the assistance is to reinforce the users' memory.

This type of assistance focuses on the first part of the wayfinding model (A- Undirected Navigation Assistance). Thus, it may improve the exploration skills: recognizing and memorizing landmarks.

4.3.2 Directed wayfinding assistance: Destination Locating

This assistance aims to help the users to reach their destination. First, it could help with locating the destination. Figure 4.4 shows how the destination could be identified for the user. When the environment is unknown (Uninformed Search: state (c) in Figure 4.1) (4.4 – left screen), the direction to the destination is displayed (the yellow flag). This may increase the users' sense of direction. When the users know their environment (Informed Search: state (d) in Figure 4.1) (Figure 4.4 – right screen), the destination could be identified near a recognized

4.3 How to improve NAS considering the wayfinding state awareness

landmark for the users. The flag could be also displayed to ensure the development of correct sense of direction.

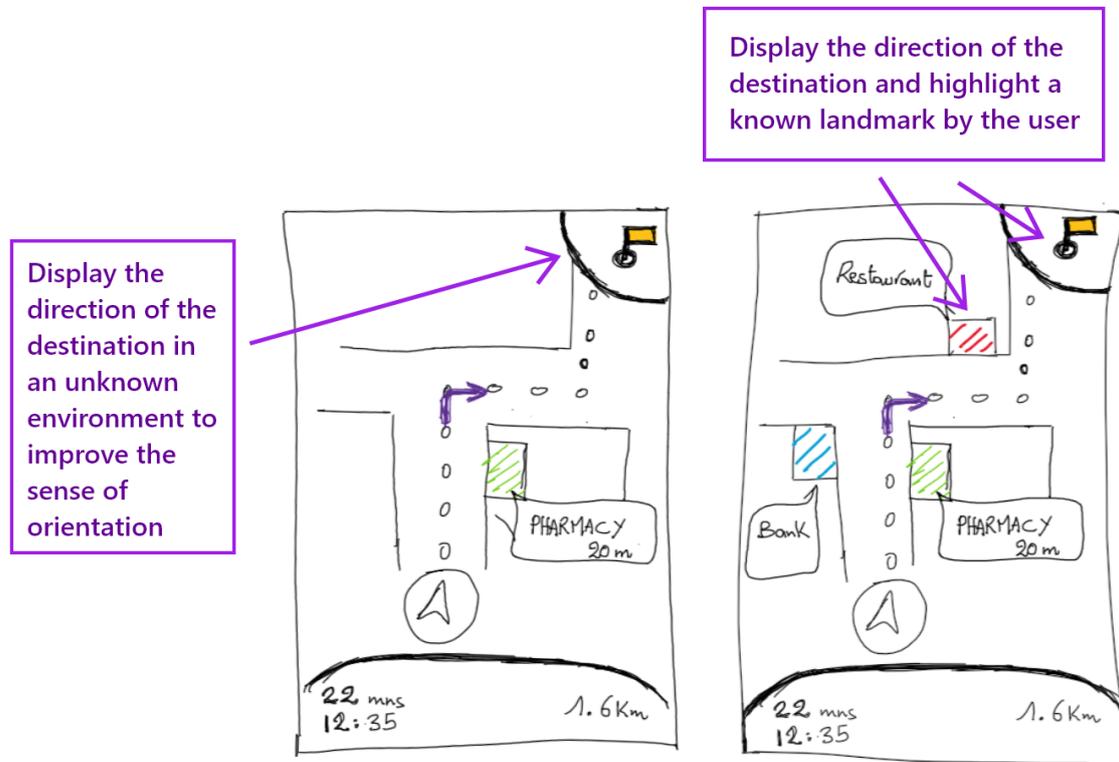


Fig. 4.4 Directed Wayfinding Assistance - Mobile Application - Destination Locating [59]

4.3.3 Directed wayfinding assistance: Path Planning & Following

The aid in this stage concerns recommending already memorized landmarks and/or visually accessible ones and also trying to include them during route planning, it means improving the user skills to link between her/his landmarks in an active way.

Second, this assistance may help also with route planning and following. The Figure 4.5 below illustrates two important recommendations that could be considered as well with the AR glasses and the other platforms of interaction mentioned in the beginning of Section 4.3:

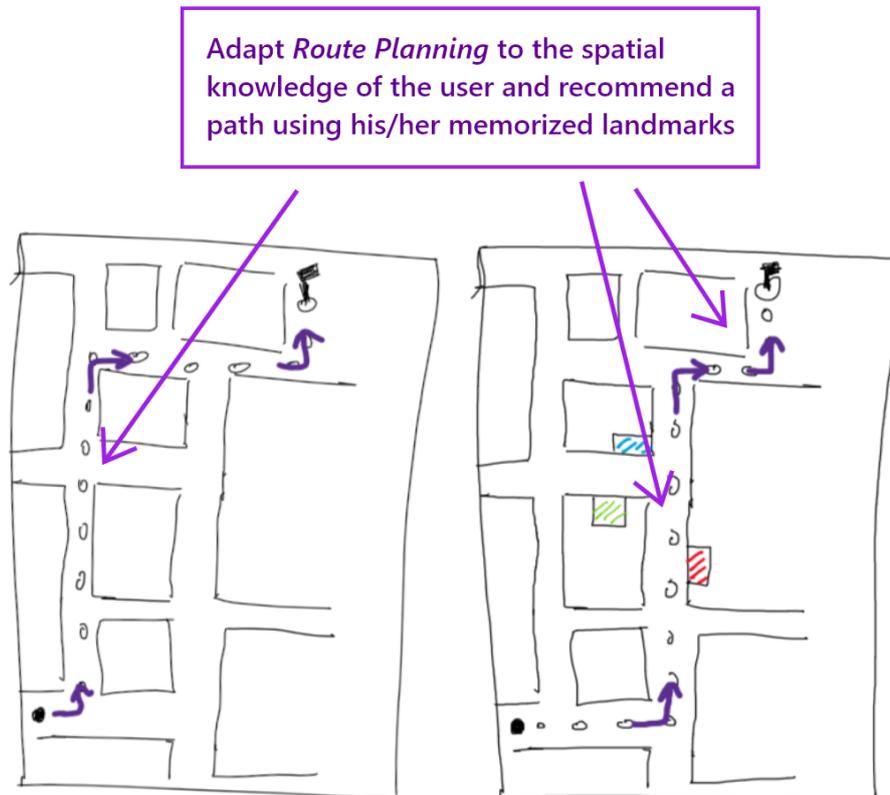


Fig. 4.5 Directed Wayfinding Assistance - Mobile Application - Route Planning [59]

- When the users are in unknown environment (*Path Search*: state (e) in Figure 4.1), the assistance could recommend a better path. This path could include relevant landmarks and easy-to-recognize ones.
- When the environment is known (*Path Planning*: state (f) in Figure 4.1), the assistance could privilege a path with memorized landmarks without affecting the user travel cost. This is especially when different paths are possible for the same destination and presenting a similar cost (for example: travel time, and/or price). It could also consider other criteria as route personal preferences (for example a quiet street).

The skills mainly targeted with this assistance are route planning, retrieving memorized landmarks and building mental route progressively. This second part of the assistance aims to assist the user starting by having a specific destination till reaching it.

The previous two subsections are explaining the wayfinding model and how it should be used to improve the current navigation aid systems. The sketches presented illustrate different situations that could be found in real life and their corresponding wayfinding state that may help to understand the need and the expectations of the user. The next subsection

will describe the prototype of one of possible systems that can be designed considering different states of the wayfinding.

4.4 A first Illustrative system of future NAS

Figure 4.6 shows the architecture of an illustrative system of future NAS using AR glasses. This system considers four main inputs:

1. User profile including their preferences that can adapt the recommendation of landmarks and presenting the user abilities for choosing adapted routes (for instance: people with ID, which is presented in Chapter 6).
2. Interaction platform used to display the guidance to the user and for this first prototype AR glasses were selected. Other platforms of interaction could be considered for the same purpose; as smartphones, smartwatches, haptic feedback belts, headphones, etc. Another possibility is to consider a multimodal interaction combining different devices.
3. Characteristics of the external environment (for example: the noise or luminosity level to adapt the user interface and ensure the most profitable experience).
4. Wayfinding model will help to identify the assistance the user may need following their current task and also in regard to different levels of their spatial knowledge which has been discussed earlier in Section 4.2.

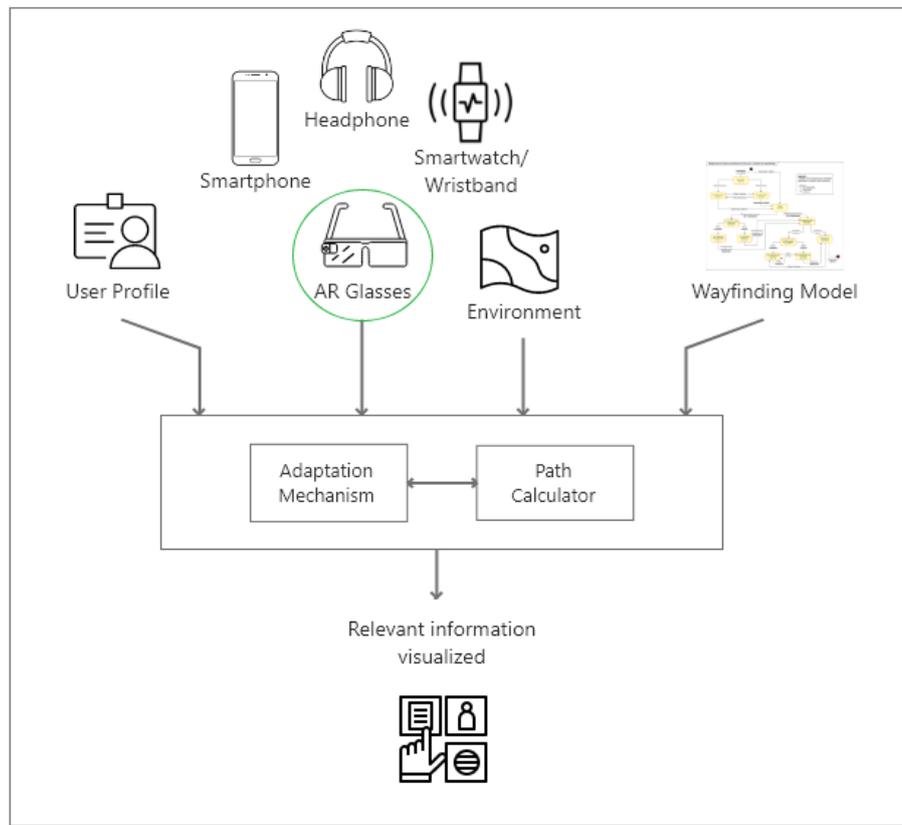


Fig. 4.6 Architecture of the first prototype using AR glasses [59]

Figure 4.7 illustrates the glasses used to build the proposed prototype. This model is the Vuzix SmartBlade AR glasses. This product received **CES 2019 Innovation Award** in recognition of its outstanding design and engineering¹. They were considered as the best compact design in 2019 and which met our needs to run this preliminary study.



Fig. 4.7 AR glasses used for this study (Vuzix Blade AR Smart Glasses)

Figure 4.8 explains the architecture of the illustrative system of navigation assistance using the glasses. The glasses are connected to a smartphone to use its GPS sensor and

¹https://d2iankuf53zudv.cloudfront.net/Content/Upload/PDFs/1_2_2019_Vuzix_Blade_CES_Award_Winner.pdf

4.4 A first Illustrative system of future NAS

to communicate also to an online API that will provide geographic information. This information is integrated into the path calculator module mentioned in Figure 4.6.

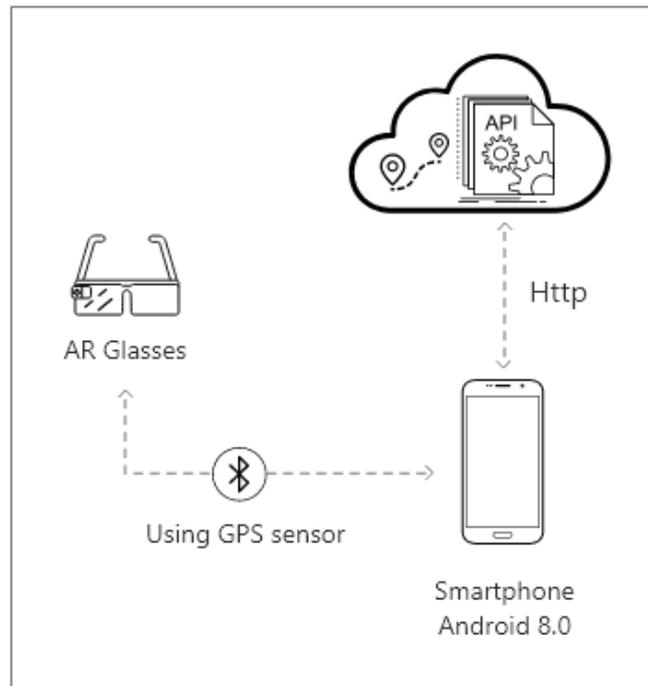


Fig. 4.8 Communication Protocols of the developed prototype [59]

Figure 4.9 is displaying a mockup of the final display to develop using these glasses and shows an example of a landmark highlighted during a real navigation task. The next section will provide further details in regard to the design and the results of this study.

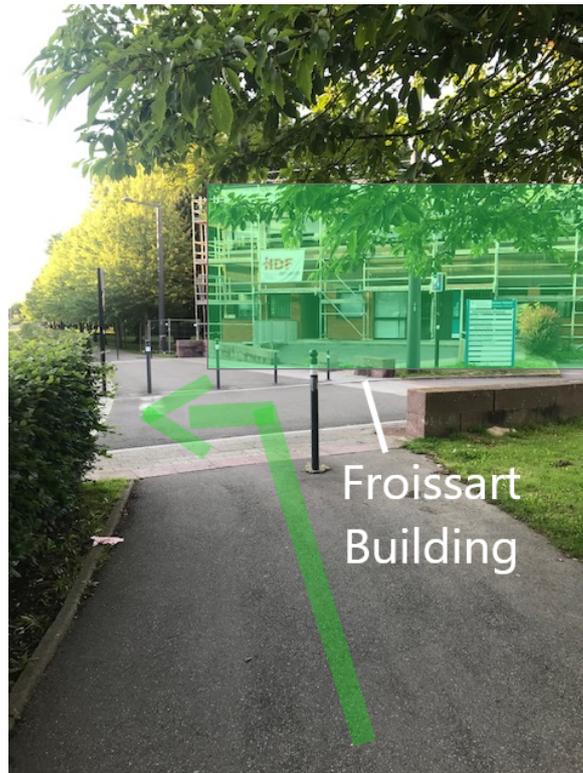


Fig. 4.9 Concept of a landmark highlighted using the AR glasses [59]

4.5 Outcomes (Illustrative study)

This section aims to demonstrate the feasibility of the approach considering one state of the wayfinding model and using AR Glasses. The results of this demonstration will initiate the choice of using AR Glasses to design adapted support for people with ID (cf. Chapter 6). The design and the results of this preliminary study are presented. The goal of this evaluation was to examine these two hypotheses:

- H1 – the user will succeed to reach the destination following the guidance including relevant landmarks provided by the AR glasses (The path following state assistance is validated).
- H2 – the user finds the AR glasses easy to use.

4.5.1 Participants

This study included 12 participants (7 females and 5 males) with an average age of 25 years old. The first section of the questionnaire (cf. Appendix B), gave to these participants before

running the experiment, helped to identify the following characteristics: 9 out of 12 have never used AR glasses but most of them were familiar with the virtual reality; 10 participants use mobile application for pedestrian navigation or while driving; 7 participants have a vision correction (min: 0.25, max: 6.0).

4.5.2 Path definition

To simulate a context of “*Path Following* (state (g) in Figure 4.1) in an unknown environment and to reach an unknown destination”, the participants were asked to follow the instructions given by the glasses starting from the laboratory to arrive to an unknown destination (the presidential building) (cf. Figure 4.10). This path was unfamiliar to all the participants. The designed system guides the users by providing instructions that include relevant landmarks at different decision points. For instance: “Turn left in front of Froissart Building” and “Turn left in front of the Gym” (cf. Figure 4.10 for the complete list of instructions).

4.5.3 Study design

The study was planned inside the campus of the UPHF (Université Polytechnique Hauts-de-France, Valenciennes), in a less frequented area. Since it is an outdoor activity, the weather state was considered to provide similar conditions for all the participants. The assistant received each participant providing a quick familiarity session using the AR glasses. This first use could help to verify the good visibility of the display. This assistant placed the participant at the depart position oriented to the initial direction. When the walk started, the assistant followed the participant from distance behind them. After reaching the destination, the participant was asked to follow the same path to return to the departure. The participant was asked to answer a questionnaire with 5 values on a Likert scale about the path followed and the usability of the system in general. Another questionnaire, adapted from the SUS (System Usability Scale²) [11, 16], was provided to the participant at two different times: before and after the walk.

²The System Usability Scale (SUS) provides a “quick and dirty”, reliable tool for measuring the usability. It consists of a 10 item questionnaire with five response options for respondents; from Strongly agree to Strongly disagree [16].

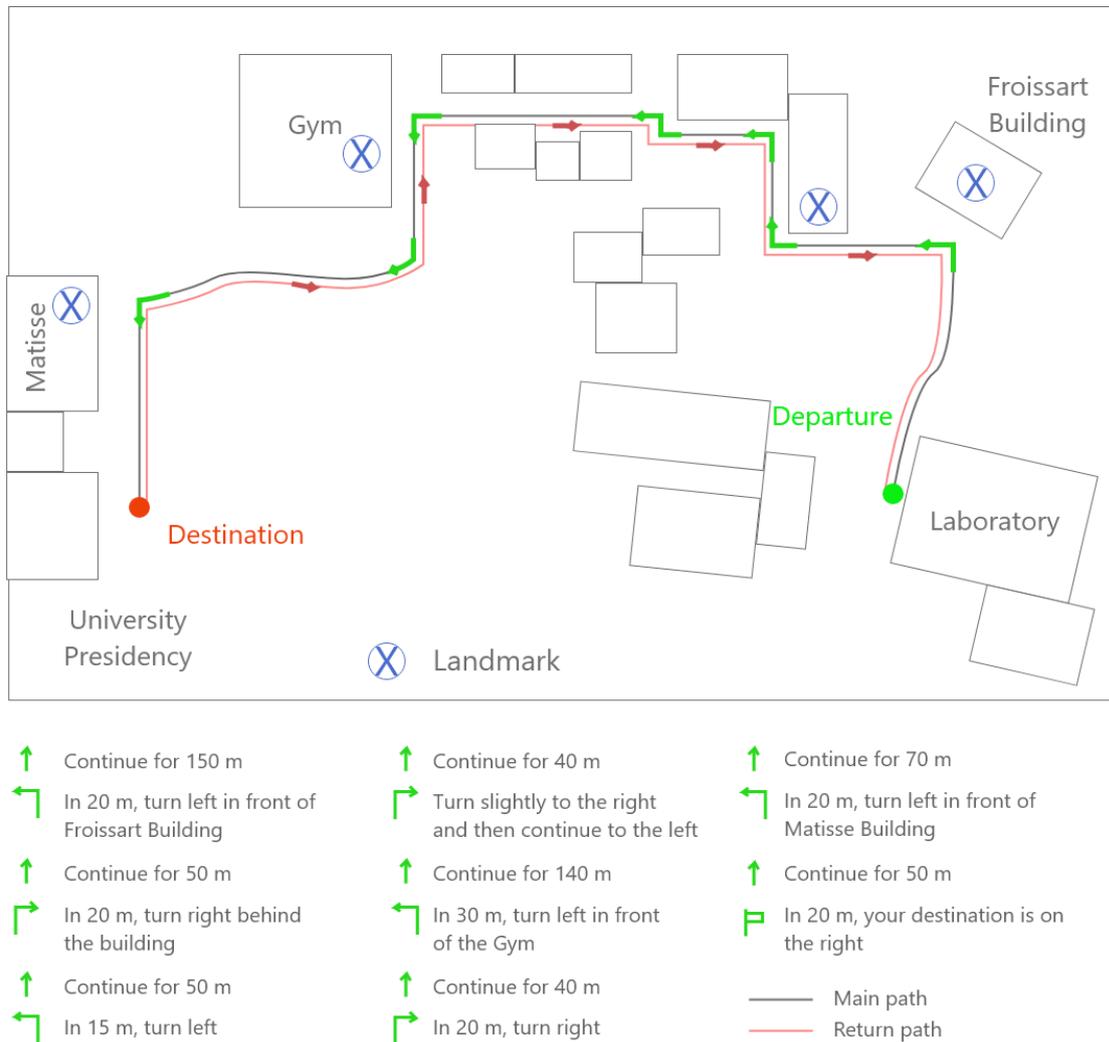


Fig. 4.10 Selected path highlighting different navigation instructions [59]

4.5.4 Results

The obtained results in regard to the SUS questionnaire are illustrated by Figure 4.11. It shows mainly the difference between the users' expectations before the experiment and their real thoughts after the short use of the glasses during the walk. It seems that the participants were more convinced of the use of these glasses after using them even for a short time (Hypothesis - H2). Two participants (number 9 & 10) had different results which can be explained: (a) The first one found that the glasses are a little bit heavier after 10 minutes of use during the navigation comparing to usual prescribed glasses. (b) The second one considered that the display was affected by the back light when facing the sunlight. So

4.6 Summary of design guidelines to improve current NAS

participants were spotted using their hands to cover the sunlight for a better vision of the display (Sunlenses were acquired after receiving this feedback).

All the participants succeeded to reach the destination without any mentioned difficulty (Hypothesis - H1). This first study confirms the feasibility of the designed system approach considering the state of wayfinding: path following. Moreover, our initial observation shows that the participants managed to return to the starting point by remembering the route. These promising findings suggest further studies to show that such an approach avoids blind navigation, while improving route learning. Finally, this study will allow to consider more states of the wayfinding model.

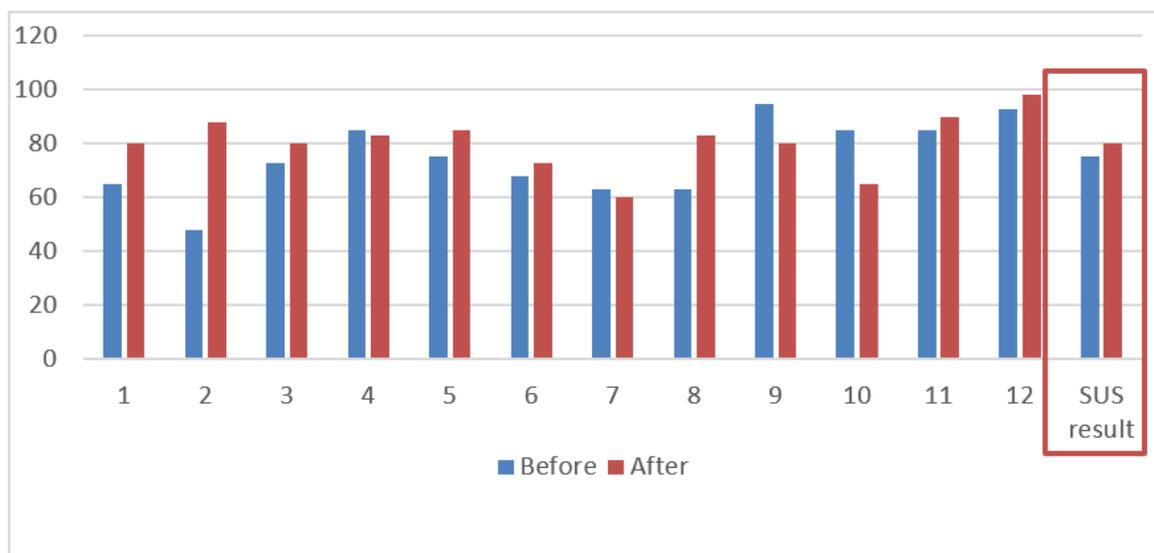


Fig. 4.11 SUS results (Before & After the use of AR glasses in mobility) [59]

4.6 Summary of design guidelines to improve current NAS

The guidelines below help to summarise different design recommendations that can help with the next generation of navigation aid systems:

- Select relevant landmarks according to the users' preferences and the history of their daily mobility.
- Highlight landmarks helping the spatial knowledge acquisition: show relevant landmarks at the right moment according to the user wayfinding's state.

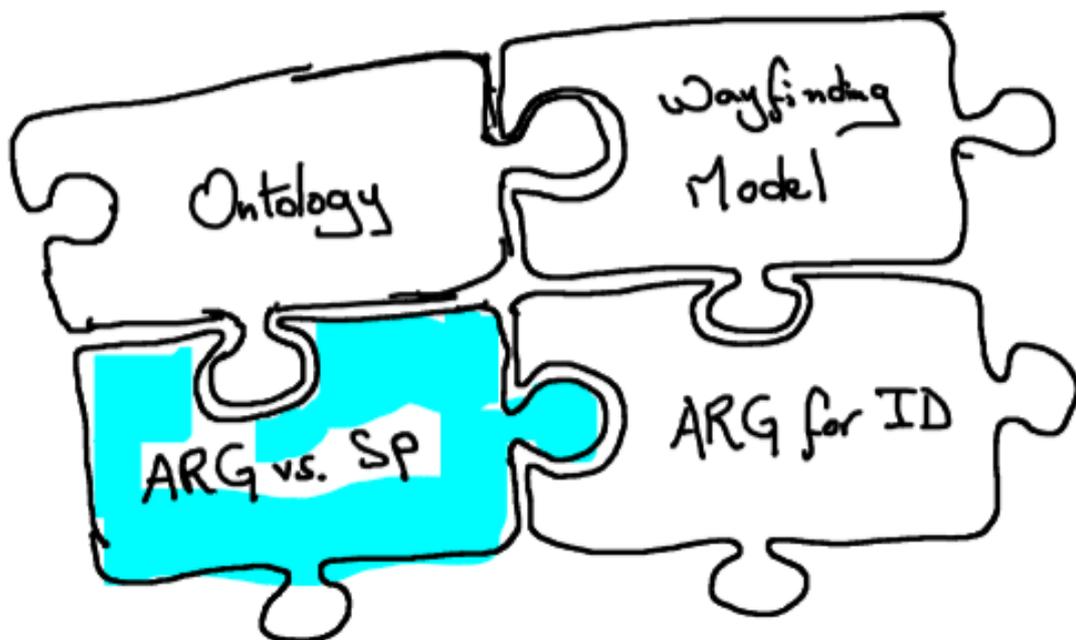
- Highlight landmarks according to the survey knowledge of the user. More landmarks are displayed when the user is familiar with the environment. Whereas, specific focus on few landmarks will be chosen when the user is less familiar with the environment.
- Display the direction of the destination to increase the sense of orientation for the user and help with the mental map construction.
- Select the best path for the user's navigation considering his or her spatial knowledge about the environment. Prioritize the most known paths for the user.
- Highlight a known landmark near the destination to invite the navigators to use their memory and their navigation skills.

4.7 Conclusion

In this chapter, the *Wayfinding model* was introduced, using a UML state diagram, representing a novel approach to design an adaptive NAS and providing more engaging experience by considering: the user profile and their preferences, the platform of interaction, and the wayfinding states. This wayfinding state awareness may be considered as a new trend for developing better NAS. The current work illustrates the feasibility of using the chosen AR Glasses, while considering the central wayfinding state: Path Following. This chapter concludes with a set of guidelines that may ensure better and more informative experience for the navigator. This cognitive model will help to anticipate the spatial knowledge inputs needed at different stages of the navigation especially for people with ID. The next chapter will expose the effects of devices like smartphones and AR glasses on navigation performance.

Chapter 5

Investigating Smartphone & AR Glasses and their Effects on Spatial Knowledge Acquisition



5.1 Introduction

Smartphone map-based pedestrian navigation is known to have a negative effect on the long-term acquisition of spatial knowledge and memorisation of landmarks. Landmark-based navigation has been proposed as an approach that can overcome such limitations. In this chapter, different interaction technologies, namely smartphones and augmented reality glasses, are investigated. This is mainly to analyse how they affect the acquisition of spatial knowledge when used to support landmark-based pedestrian navigation. A study was conducted, in the university of Kent (Canterbury, UK) in collaboration with the co-authors of [57], involving 20 participants, using smartphones or AR glasses for pedestrian navigation (cf. published protocol in [57]). The effects of these systems in landmark memorisation and spatial knowledge acquisition were studied over a period of time. The last section presenting the results shows statistically significant differences on the spatial knowledge acquisition with both technologies, with the AR glasses enabling better memorisation of landmarks and paths. The conclusion will give an idea about the device selection to pursue the NAS design for people with ID.

5.2 Research collaboration with the University of Kent

During the Phd thesis, the research team from the Université Polytechnique Hauts-de-France has collaborated with researchers from the University of Kent through 6 phases:

- **Phase 1 (21/08/2019 – 24/08/2019):** after a first contact by email to apply for the scholarship, from I-site ULNE Foundation, the first visit to Canterbury for 3 days took place. It helped to align on the collaboration goals, with Christos Efstratiou and Rocio von Jungendorf, and how the collaboration can continue remotely.
- **Phase 2 (24/08/2019 – 16/10/2019):** during this time, the study protocol was elaborated through virtual meetings involving: Christos Efstratiou, Pavlos Nicolaou, Mayank Loonker.
- **Phase 3 (16/10/2019 – 02/11/2019):** this is the second visit to the University of Kent. During this visit, the setup of the study was finalised and the conduction started on the second week.
- **Phase 4 (02/11/2019 – 03/02/2020):** first data analysis were started and the researchers in Canterbury conducted the second phase of the study (second walk, more details are present in the study design section).

- **Phase 5 (03/02/2020 – 15/02/2020):** third visit to the Kent with the goal of reiterating on the first results of the study, cleaning the data and replace few participants due to quality concerns.
- **Phase 6 (15/02/2020 – 19/06/2020):** last remote phase was dedicated mostly to discuss the results and co-write a scientific paper published in MobileHCI 2020 [57].

More visits were planned but canceled due to the COVID pandemic.

5.3 Method

5.3.1 Path Definition and Landmark selection

The selection of the location for conducting the experiment can have a significant effect on the results. The goal was to select a path in an unfamiliar area for the participants, without very distinctive landmarks. It should present a level of challenge for people to navigate through without technology. A residential area was identified following informal surveys of the authors' social network. The location, is withing Canterbury, a small British town, away from popular walking routes. This area is described as "difficult to navigate" by local residents. It consists of similar looking residential buildings (Figures 5.1 and 5.2).



Fig. 5.1 Footpath between the residential buildings of the study area.

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Fig. 5.2 Residential buildings

By relying on local knowledge, 12 residents (6 females) were asked to fill a questionnaire (cf. Appendix C) in order to identify relevant landmarks in their local area and thus to help define a landmark-based navigation path. Questions that were asked included: "A person new to this area is asking you for guidance; what landmarks would you use to guide them?", "Please suggest a path between location A (departure) and B (destination) and highlight what landmarks you would use for guidance" (used for multiple A-B combinations). This survey allowed to use local knowledge in selecting a path, and defining landmarks that would make sense for a pedestrian in that area. The categories of landmarks identified by local residents are illustrated in Figure 5.3. Combining this information, and the suggested navigation advise by local residents, the path was defined within that area, and the relevant landmarks for navigation (Figure 5.4).

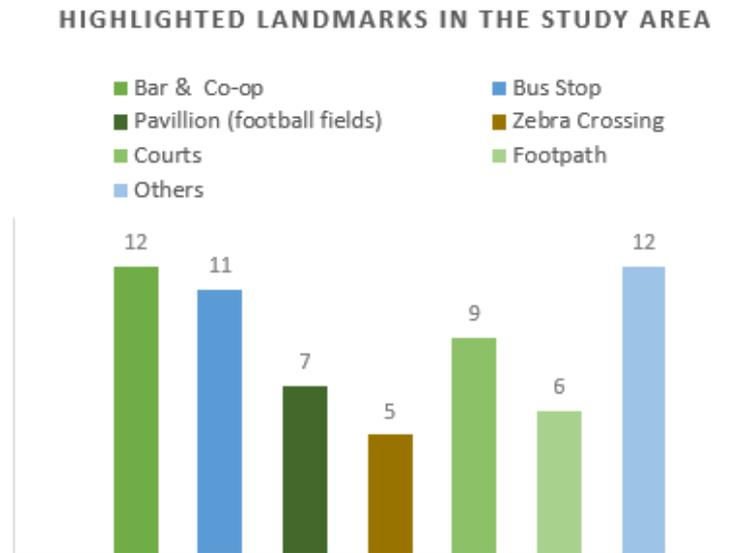


Fig. 5.3 Highlighted landmarks in the targeted residential area.

Guidance Instructions:

- 1- Turn Left and follow the Footpath
- 2- Cross the road on the Zebra Crossing
- 3- Turn Left after the Phone Booth
- 4- Turn Right when you see the bus stop
- 5- Slide Right in front of Woody's Bar
- 6- Continue Straight over the Zebra Crossing
- 7- Turn Right after Bishopden Court
- 8- Follow the main road
- 9- Your Destination is on the Right

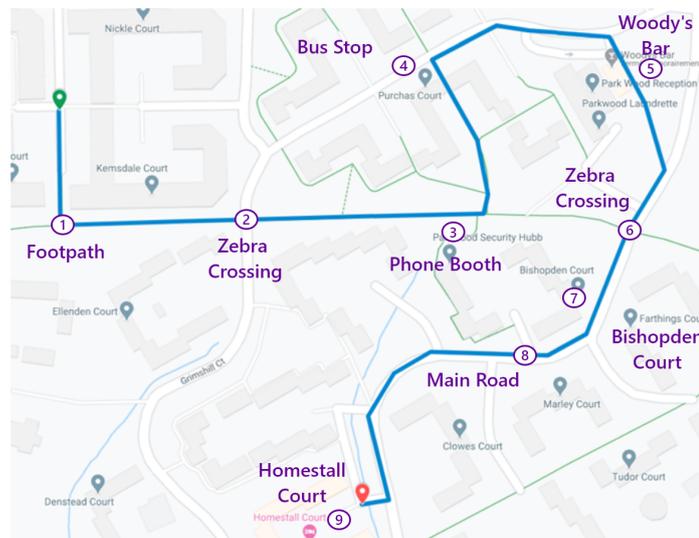


Fig. 5.4 Selected Path with different landmarks and guidance instructions

5.3.2 Navigation App

Relying on previous information including identified landmarks, a navigation mobile app was constructed to provide assistance for users finding their way through the defined path. The application was designed to offer the same type of functionality and similar visual clues on both smartphones and AR glasses (cf. Figure 5.5 & 5.6). The app displays suitable

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navigation advise when a user approaches a decision point (Figure 5.7); it is based on the current location of the user retrieved from GPS tracking.



Fig. 5.5 Mobile Phone Application displaying the instruction: "Turn Left after the Phone Booth in 20 meters"



Fig. 5.6 AR Glasses Application displaying the instruction: "Turn Right when you see the Bus Stop in 30 meters"

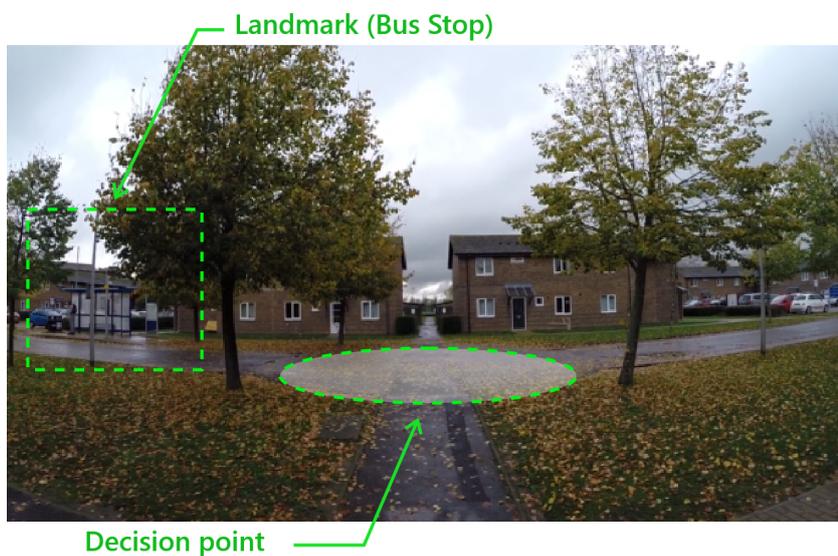


Fig. 5.7 Decision Point illustrating a landmark (Bus Stop)

The design of the app is driven by prior research in the areas of cognitive mapping, wayfinding and route instructions design [108, 116, 21]. Navigation routes are often explained as a sequence of turns or changes in direction during decision points, over a navigation path. The navigation app that was developed for this study, involves the delivery of precision

textual guidance with an orientation indicator, which is triggered when the user approaches decision points. Landmarks are included into the guidance instructions to give most relevant information. The aim is to reduce the cognitive load that is required for the user to engage with the app, and allow them to focus more on their surroundings, and give them the opportunity to build their own perception of the environment. Further design recommendations were considered while designing the AR glasses application. For instance, the display colour was selected to be green [32], and information was positioned at the bottom center of the in-glass screen, to support the highest comprehension [100] and to ensure a clear view of the walking path.



Fig. 5.8 Sequence of instructions displayed when the user is approaching a decision point.

The navigation assistance was manually constructed by including navigation advice using landmarks. Different decision points from the navigation path were connected and encoded into the app from the previous information. These points consist of where the user is expected to decide for any changes in their direction. The app offered relevant prompts, with references to local landmarks, visible at each decision point. Figure 5.8 illustrates a sequence of instructions displayed on the AR glasses when the user is approaching a decision point. The described process is the same on the smartphone.

The system shows a navigation advice highlighting the selected landmark when the user is approaching a decision point (cf. Figure 5.8 number 3). After confirming that the user took the correct decision using GPS tracking, the system updates the targeted decision point with the next point.

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5.3.3 Study Design

The study was conducted in Autumn 2019. The study included 20 participants (10 females), age range 21-39 (median: 25.5). The participants were split into two groups: SP group was given the smartphone version of the navigation system to use during their first walk, and ARG group was given the AR glasses version. All participants were asked to take the Santa Barbara Sense of Direction Scale (SBSDS) test [70]. When splitting the groups, similar distribution of SBSDS scores for both groups was respected. First, each participant was allowed 3-4 minutes of becoming familiar with the technology. The AR glasses are a novel technology, and this can affect the perception and interaction of the user with them. Although the familiarisation task may not be sufficient to avoid the novelty factor completely, but it ensures that participants felt comfortable with them.

Each participant navigates through the path following the guidance provided by the system. They were asked to fill a usability questionnaire, the SUS (System Usability Scale) [11, 16], before and after performing the first walk. At the end, they answer a memory test by plotting the path and marking memorised landmarks (cf. Figure 5.10 and Appendix D). A second walk was planned after one week and it involved two memory tests, before and after the walk. Participants were not given an explicit interdiction for visiting the area between both walks. However, they have been made aware of the importance of avoiding the area during the entire duration of the study and how it may affect the memorisation results. The experiment procedure is illustrated with Figure 5.9.

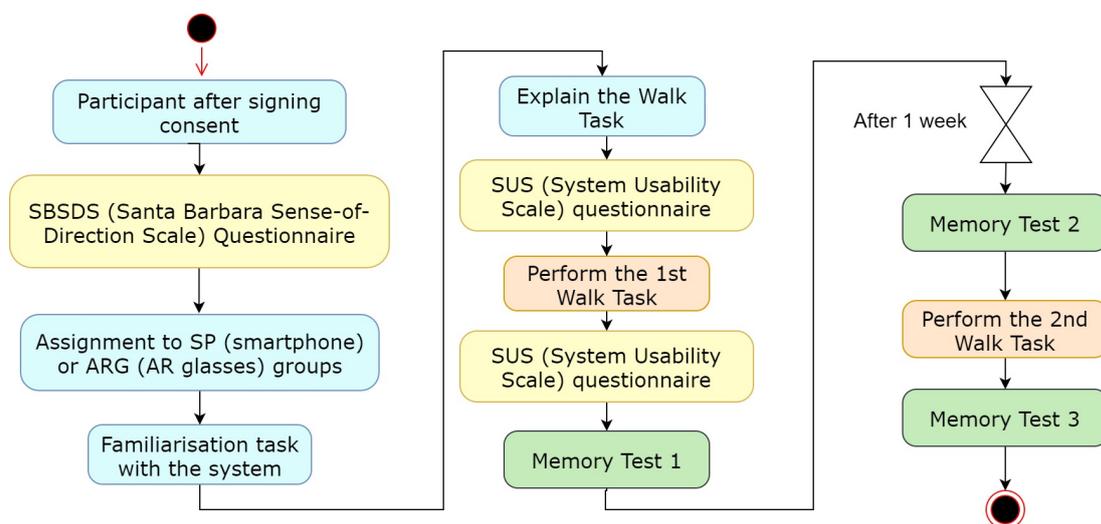


Fig. 5.9 Activity diagram of the protocol

5.3.4 Data capture

The experimental protocol, as described earlier, consists of asking each participant to walk through the same path twice. The first time, using a navigation assistance (an app installed on a smartphone or AR glasses). The second time, without using any device. Number of datasets have been collected during the study to address the defined research questions.

Each participant were asked to answer the SUS questionnaire, before and after using the technology for the walk. This subjective assessment of the technology could help to explore correlations with the effects in spatial knowledge acquisition.

The Santa Barbara Sense of Direction Scale (SBSDS) survey offers an indication on the inherent sense of direction of each participant. The SBSDS questionnaire is used to evaluate the spatial abilities of the participants. Based on these results, participants were allocated to the two groups to ensure a balanced representation of abilities. The findings, using a Welch's t test, showed no significant difference between the two groups in terms of spatial navigation and sense of orientation abilities.

A key dataset in this experiment involves a number of memory tests that participants were asked to perform after the first walk, and a week later before and after they performed the walk without any technology. The aim of the memory test is to capture the participant's recall of landmarks, and to test their abilities in spatial transformation as an indication of spatial knowledge acquisition [99]. Specifically, participants were asked to plot their walk on a map, as way of mentally changing their perspective of the environment (transformation), and to indicate the location and type of landmarks along the path (cf. Figure 5.10).

5.4 Results & Evaluation

The primary objective of this study was to test the hypothesis: « After using landmark-based navigation technologies, **AR Glasses**' experience supports landmark memorisation more effectively than **Smartphones** ».

5.4.1 Santa Barbara Sense of Direction Scale (SBSDS)

Table 5.1 and 5.2 present the results of the SBSDS questionnaire. By using Welch's t test on this data, no significant difference was found between both groups ($t=1.7$, $p > 0.0991$), where the SBSDS score for ARG group was ($M = 69$, $SD = 8.1976$) and the SBSDS score for SP group was ($M = 61.5$, $SD = 9.9725$).

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Participant	ARG1	ARG2	ARG3	ARG4	ARG5	ARG6	ARG7	ARG8	ARG9	ARG10
SBSDS	81	63	67	76	83	57	72	62	65	64

Table 5.1 SBSDS score for ARG group

Participant	SP1	SP2	SP3	SP4	SP5	SP6	SP7	SP8	SP9	SP10
SBSDS	68	64	80	65	58	57	47	44	65	67

Table 5.2 SBSDS score for SP group

5.4.2 System Usability Scale (SUS)

This questionnaire helps to obtain a subjective estimation of the system usability. Table 5.3 illustrates descriptive statistics of the SUS results for both groups before and after the use of the navigation system. It shows that participants in both group gave a better score after using the technology.

Group	ARG (Before)	ARG (After)	SP (Before)	SP (After)
M	66.25	73.50	68.25	75.25
Med	62.50	76.25	67.50	77.50
Min	32.50	37.50	52.50	50.00
Max	92.50	92.50	92.50	92.50
SD	21.87	16.72	9.93	11.81

Table 5.3 SUS score summary for ARG and SP groups

5.4.3 Memory Tests

In this section, the memorisation results are analysed following three steps: starting first with (1) landmarks than (2) path segments, and finally (3) global memorisation score including landmarks and path segments.

Landmarks memorisation:

Figure 5.10 illustrates the results of one memory test with a plotted path and landmarks located along this path. To evaluate the performance of the participants, a memorisation score for landmarks (MS_L) was calculated based on identified landmarks; three values are possible for each landmark (0: not located at all, 1: incorrectly located, 2: correctly located). For example, Table 5.4 shows the results of participant SP8 (using a smartphone), they succeeded to recall 4 landmarks out of 9, in the 1st test, where 2 of them were positioned correctly on the map. The complete results are illustrated in Table 5.10 and 5.11.

Example of landmarks:

- Court
- Bar
- Zebra Crossing
- Laundry
- Bus Stop
- Sports field
- Footpath
- Nursery
- Stream/river
- Reception building

Road
 Footpath
 Departure point
 Start orientation

Instructions

- Draw the path you were navigating through.
- Mark the landmarks you remember from the list above (the list may contain odd elements).
- Feel free to add any comments on the other face.

For more details on the study, please refer to: <https://arexperiment.wordpress.com/>



Fig. 5.10 Memory Test 1 for participant SP8

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Landmark	Footpath	Zebra Crossing	Phone Booth	Bus Stop	Woody's Bar	Zebra Crossing	Bishopden Court	Main Road	Hemsdell Court
Notation	L1	L2	L3	L4	L5	L6	L7	L8	L9
M. Test 1	0	2	0	1	2	1	0	0	0
M. Test 2	0	2	0	1	2	0	0	0	0
M. Test 3	0	2	0	1	1	0	0	0	0

Legend: 0: not located at all, 1: incorrectly located, 2: correctly located

Table 5.4 Evaluation of landmarks memorisation (Participant SP8)

Participant	ARG1	ARG2	ARG3	ARG4	ARG5	ARG6	ARG7	ARG8 ¹	ARG9	ARG10
ARG M. Test 1	8	12	9	10	11	12	5	nan	12	7
ARG M. Test 2	8	13	8	9	11	8	4	nan	10	6
ARG M. Test 3	9	13	8	8	13	2	7	nan	12	10

Table 5.5 Memory Tests: landmarks results for ARG group (the score is in a range of 0 to 18)

Participant	SP1	SP2	SP3	SP4	SP5	SP6	SP7	SP8	SP9	SP10
SP M. Test 1	10	6	7	4	12	8	7	6	2	11
SP M. Test 2	6	7	7	7	6	8	9	5	1	5
SP M. Test 3	6	7	2	7	6	10	11	4	3	8

Table 5.6 Memory Tests: landmarks results for SP group (the score is in a range of 0 to 18)

¹Due to technical issues, this participant did not manage to complete the memorisation task and with the current circumstances, it was impossible to have a new participant in the past few months. With the statistical Welch's t test, it was possible to proceed with the analysis despite having two different groups in term of size.

With a Welch’s t test, no significant difference was found between both groups except for the second test ($t=2.1897$, $p < 0.0442$), where the score of located landmarks for ARG group ($M = 8.6$, $SD = 2.4994$) was larger than the score of located landmarks for SP group ($M = 6.1$, $SD = 2.0712$).

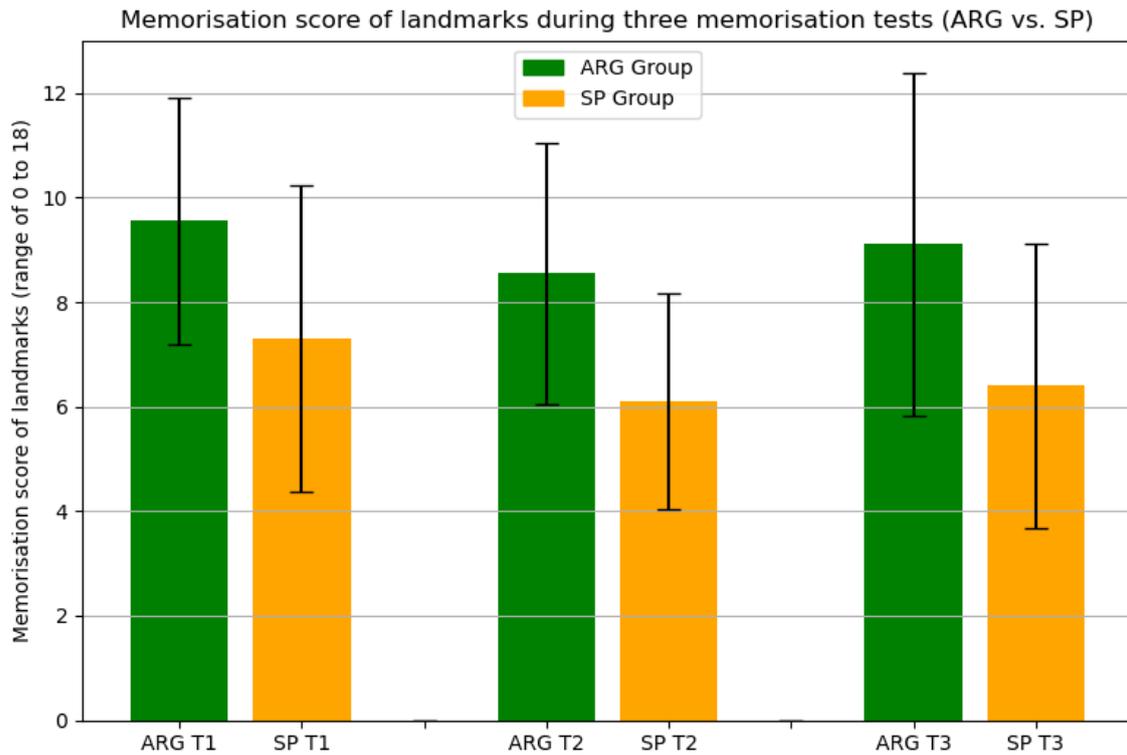


Fig. 5.11 Memorisation Score Analysis (Landmarks)

Figure 5.11 illustrates the results of analysing landmarks memorisation. It shows that participants of ARG group were performing better in terms of memorisation comparing to the ones of SP group. Thus, AR glasses supports landmark memorisation more effectively than smartphones.

Path segments memorisation:

The next step is to consider the accuracy of the plotted path by calculating a memorisation score MS_S of recalled segments (each segment is located between two decision points, i.e. between two landmarks). Table 5.7 illustrates the corresponding score for participant SP8 (1: correct segment, 0: incorrect segment). Table 5.8 and 5.9 illustrate the results of both groups. By using the Welch’s t test on these data, no significant difference was found between both groups in terms of memorising path segments. Figure 5.12 illustrates these results that show no significant difference between both devices in supporting path segments memorisation.

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Segment	Departure - L1	L1 - L2	L2 - L3	L3 - L4	L4 - L5	L5 - L6	L6 - L7	L7 - L8	L8 - L9	MS_S
M. Test 1	1	1	1	1	1	1	0	0	0	6
M. Test 2	1	1	1	1	1	1	1	0	0	7
M. Test 3	1	1	1	0	1	1	1	0	0	6

Table 5.7 Evaluation of segments memorisation (Participant SP8)

Participant	ARG1	ARG2	ARG3	ARG4	ARG5	ARG6	ARG7	ARG8	ARG9	ARG10
ARG M. Test 1	8	9	8	7	9	9	3	nan	9	7
ARG M. Test 2	9	9	9	7	9	9	3	nan	9	8
ARG M. Test 3	9	9	9	7	9	9	5	nan	9	9

Table 5.8 Memory Tests: segments results for ARG group (the score is in a range of 0 to 9)

Participant	SP1	SP2	SP3	SP4	SP5	SP6	SP7	SP8	SP9	SP10
SP M. Test 1	7	6	4	4	7	8	5	6	7	8
SP M. Test 2	7	6	4	4	7	8	7	7	4	8
SP M. Test 3	7	6	6	5	7	8	7	6	8	9

Table 5.9 Memory Tests: segments results for SP group (the score is in a range of 0 to 9)

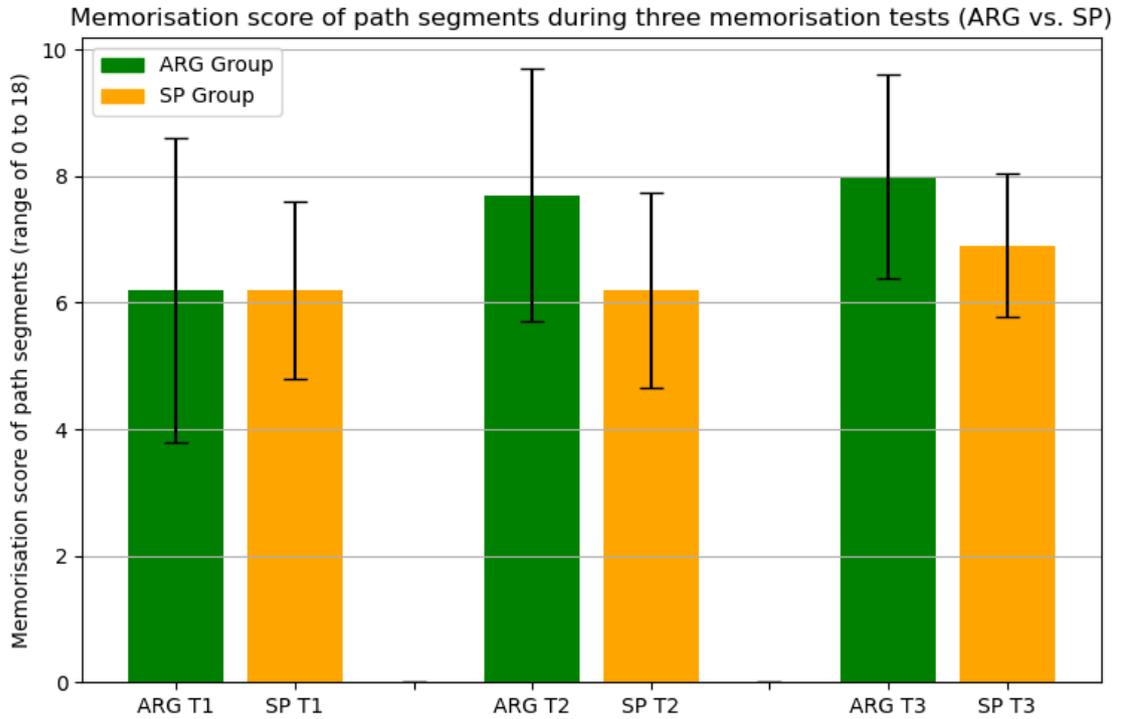


Fig. 5.12 Memorisation Score Analysis (Path segments)

Landmarks and path segments memorisation combined:

Both obtained results from the previous analysis (landmarks and segments) were combined to calculate a global memorisation score MS (cf. Table 5.10 and 5.11). The scaling method, described below, was used to bring the results to the same range between 0 and 5. Then, the MS score was calculated by aggregating the scaled scores and thus, MS will be in a range of 0 to 10 (lowest and highest score of global memorisation respectively).

- r_{min}, r_{max} denote the minimum and the maximum of the range of the measurement
- t_{min}, t_{max} denote the minimum and the maximum of the range of the desired target scaling

$$scaled_score = \frac{score - r_{min}}{r_{max} - r_{min}} (t_{max} - t_{min}) + t_{min}$$

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Participant	ARG1	ARG2	ARG3	ARG4	ARG5	ARG6	ARG7	ARG8	ARG9	ARG10
ARG M. Test 1	6.67	8.33	6.94	6.67	8.06	8.33	3.06	nan	8.33	5.83
ARG M. Test 2	7.22	8.61	7.22	6.39	8.06	7.22	2.78	nan	7.78	6.11
ARG M. Test 3	7.5	8.61	7.22	6.11	8.61	5.56	4.72	nan	8.33	7.78

Table 5.10 Memory Tests: global score results for ARG group (the score is on a scale out of 10)

Participant	SP1	SP2	SP3	SP4	SP5	SP6	SP7	SP8	SP9	SP10
SP M. Test 1	6.67	5.0	4.17	3.33	7.22	6.67	4.72	5.0	4.44	7.5
SP M. Test 2	5.56	5.28	4.17	4.17	5.56	6.67	6.39	5.28	2.5	5.83
SP M. Test 3	5.56	5.28	3.89	4.72	5.56	7.22	6.94	4.44	5.28	7.22

Table 5.11 Memory Tests: global score results for SP group (the score is on a scale out of 10)

By using the Welch's t test, significant difference was found between both groups for the 2nd and the 3rd memory tests. The obtained results for these two tests were respectively (M. Test 2: $t=2.4$, $p < 0.0279$) and (M. Test 3: $t=2.6$, $p < 0.0195$), where the global score MS for ARG group (M. Test 2: $M = 6.821$, $SD = 1.6039$) and (M. Test 3: $M = 7.16$, $SD = 1.3205$) was larger than the global score of SP group (M. Test 2: $M = 5.141$, $SD = 1.1672$) and (M. Test 3: $M = 5.611$, $SD = 1.1088$).

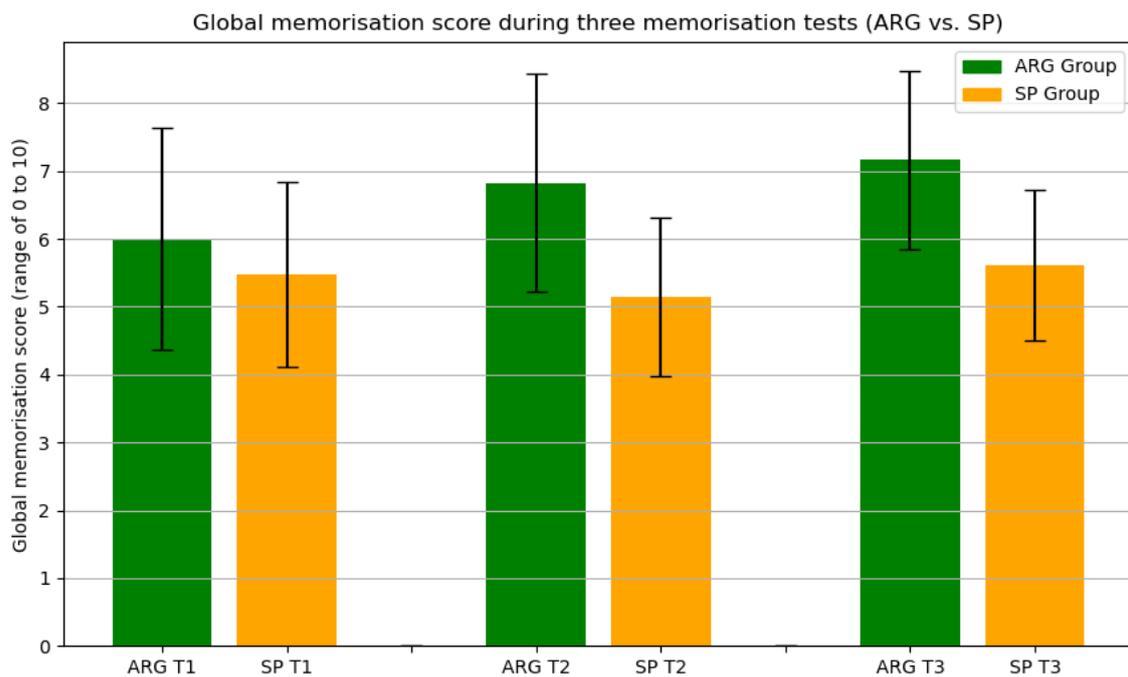


Fig. 5.13 Memorisation Score Analysis (Landmarks + Path segments)

Figure 5.13 illustrates the results of analysing memorisation score (MS). It shows that participants of ARG group were performing better in terms of path memorisation comparing to the ones of SP group. Thus, AR glasses supports path (landmarks + segments) memorisation more effectively than smartphones.

5.5 Discussion

Traditional navigation aid systems are known for being less efficient when it comes to spatial knowledge acquisition. This chapter aimed to explore the use of landmark-based assistance, as stated by other researchers [103, 79] and proven its benefit for memorising paths and survey knowledge. Its objective is to investigate AR glasses and smartphones for pedestrian navigation and their effects on spatial knowledge acquisition. The results indicate that people,

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using AR glasses, were performing better in terms of landmarks memorisation, comparing to smartphones.

In line with the defined hypothesis: “After using navigation technologies, **AR Glasses**’ experience supports landmark memorisation more effectively than **Smartphones**“, the memory tests analysis shows that AR glasses offer a better support for landmarks memorisation and also for survey knowledge acquisition after combining both memorisation scores.

Comparison with Previous Work and Contribution. The main contribution in this work is to investigate the effects of AR glasses comparing to smartphones on spatial knowledge acquisition. This research question has not been addressed before using a similar approach. Previous studies compared navigation devices without considering evaluating the memorisation task and for those who did, the AR experience was limited to a smartphone support.

Our results show that AR glasses can be a suitable support to provide an active landmark-based assistance for pedestrian navigation. It offers a better experience favouring spatial knowledge acquisition. It is legitimate to expect that using similar systems will help people to gain improved spatial awareness and creating more autonomy for their mobility.

Limitations and Future Studies The generalizability of the results is limited by having two groups with a different size for the memory test. In addition, our study considered navigating two groups of people through one single path. Despite these limitations, the obtained results are valid to answer the research question and support our hypothesis. The statistical method used was insensitive to the difference of groups sizes. Moreover, the navigation path was identified following a rigorous method basing on local residents knowledge and expertise in the area.

5.6 Conclusion

Regarding the negative effects of passive assistance offered by most of current navigation systems, the use of landmarks by future systems let envisage new perspectives for pedestrians. With this aim, new types of technologies have to be designed and evaluated.

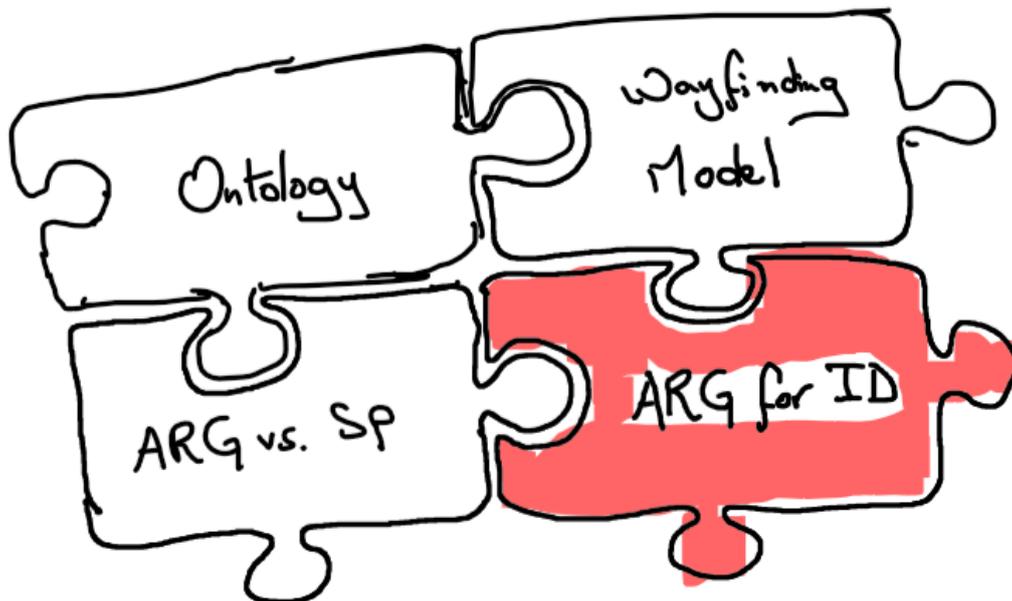
This chapter has described our contribution through a comparative study, conducted in the university of Kent, of two navigation technologies (smartphones and AR glasses) that can facilitate path memorization. The participants of each of the two groups were asked to walk through the same path twice, the first one using a navigation assistance installed on one of the devices, the second time without any device. The SBSDS questionnaire has been initially used to evaluate the spatial abilities of the participants who were equally allocated to the two groups. Each participant had to perform memory tests about the landmarks used and the pathway followed after the first walk, and a week later before and after they

5.6 Conclusion

performed the walk without any assistance. The results obtained show that the performance of the participants was better in term of path memorisation using AR glasses rather than smartphones. This chapter helps to backup the choice of AR glasses for NAS design which will be adapted to people with ID. This system will be the main focus of the next chapter.

Chapter 6

Pedestrian Navigation Assistance for People with ID using AR Glasses



6.1 Introduction

As discussed earlier in the state of art (Section 2.7), the existing navigation assistance solutions for people with ID are far from being sufficient. These systems are whether focused on directive guidance without a window for developing the user independence, or restricted to few wayfinding states.

In order to design a system which fits the best the targeted population's needs, a collaboration has been established with the "UDAPEI du Nord¹". This organisation supports thousands of people mainly with intellectual disability, learning disability and autism. This collaboration offers an access to its population as potential users. In this work, the first collaboration was done closely with one of its institutions: IMPRO² in Wahagnies (France) that supports almost 100 adolescents. The IMPRO was chosen as a leading study field because of its different services (for instance: different workshops to acquire daily life skills, and Transport & Mobility was one of them). This institution also allows for running experiments in their local private space despite the COVID restrictions. This facility has roads, sidewalks and road signs within its private space. Further details are given in the next sections.

The previous chapters (3, 4 and 5) helped to demonstrate the followed process during the last three years. This chapter brings the last piece to this puzzle. It allows to utilise the ontology concepts, to consider the wayfinding states and to employ one device that demonstrated its efficiency. This final piece explains how a navigation system could be designed and built for people with intellectual disability.

This last chapter of the contribution is divided into three main sections. Methodology, as a first one, gives an overview of different studies put in place in order to achieve the expected outcome. Then, it comes the section where the design of the system and different studies is illustrated. Finally, the results are summarised and presented.

6.2 Methodology

This section illustrates the main steps of designing the navigation aid system. This methodology considered adapted steps in order to collect user needs [9, 105]. As displayed in Figure 6.1, it started first with building a collaborative and trustful relationship with the adolescents and their trainers. Second, participatory design workshops were led to gather inputs of the potential users in order to adapt the system design. Finally, two studies were performed to assess the performance of the system.

¹a regional representative of the UNAPEI

²Institut Médico-Professionnel (Medical and Professional Institution)

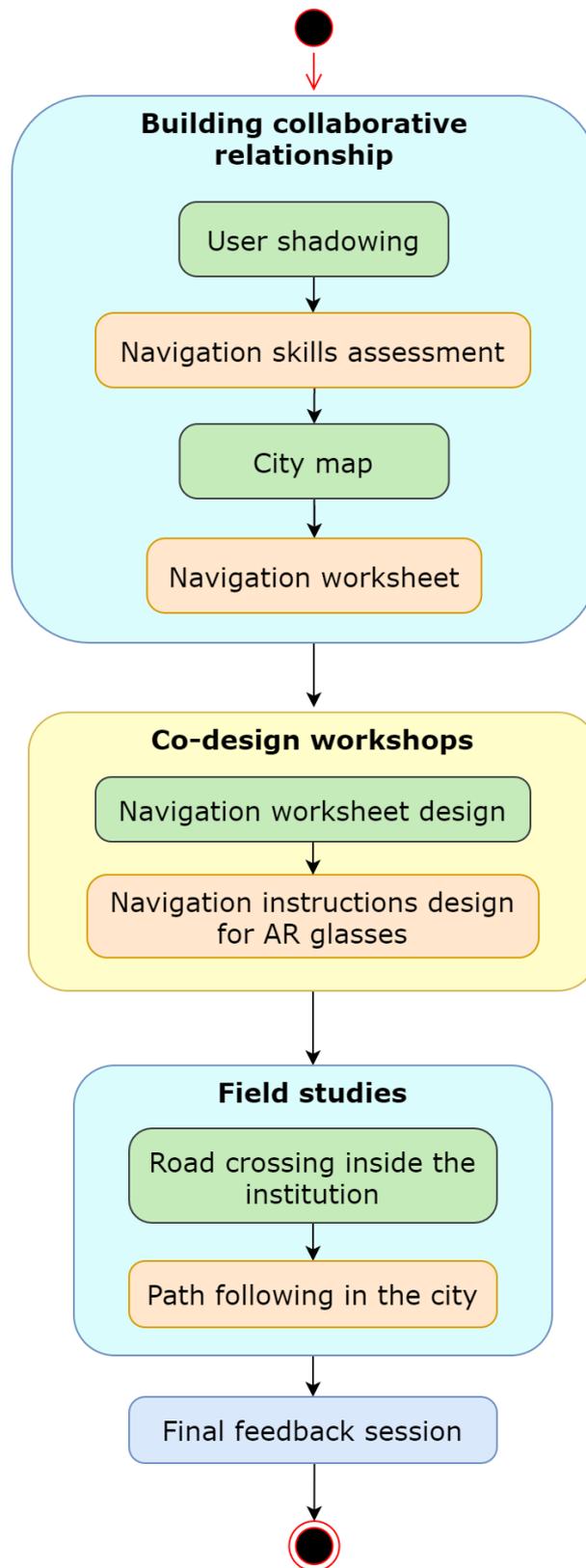


Fig. 6.1 Main steps of the research methodology

6.2.1 Building collaborative relationship

This initial step aimed to help the research team to get familiar with the young children and their trainers. This essential step offered the opportunity to observe and understand their interactions during transport & mobility workshops. This phase allowed also to discover the materials (for example workshops worksheets). In order to build a trustful and open connection with the potential users (young children) and the stakeholders (trainers and the institution professionals), four activities were put in place:

1. **User shadowing:** this was the beginning of the collaboration. It consisted of observing the children (4 to 6 participants) during their daily workshops/lectures and trying to analyse their interactions. This could be summarised through these actions:
 - Attend 4 weekly workshops (3 hours each, on Monday afternoon)
 - Try to have small talk with different people
 - Discover learning methods and materials
2. **Navigation skills assessment:** the goal of this exercise was to assess the navigation skills of the young children (4 workshop attendees). It consisted of asking participants to find a path passing by few landmarks and reaching a specific destination. The participants were fully autonomous inside the IMPRO institution. The navigation task would require skills as path planning, path following, landmarks recognition and memory recall of spatial knowledge to draw the path on a map. Figure 6.2 illustrates IMPRO's plan for this assessment.



Fig. 6.2 Plan of IMPRO for the navigation assessment

3. **City map:** this workshop consisted of using a city mockup (cf. Figure 6.3). The goal was to review safety instructions learned in a previous session. The 4 participants had to move a human-like figurine to reach a given destination while respecting and explaining different safety measures.



Fig. 6.3 City mockup for the workshop

4. **Navigation worksheet:** the research team worked closely with the trainers in order to design a navigation worksheet (cf. Figure 6.4 and for complete version, Appendix H). This worksheet consisted of a map illustrating different situations for road crossing on an intersection. Each participant was asked to make the right decision on the navigation path following safety recommendations. This workshop involved 3-5 participants.

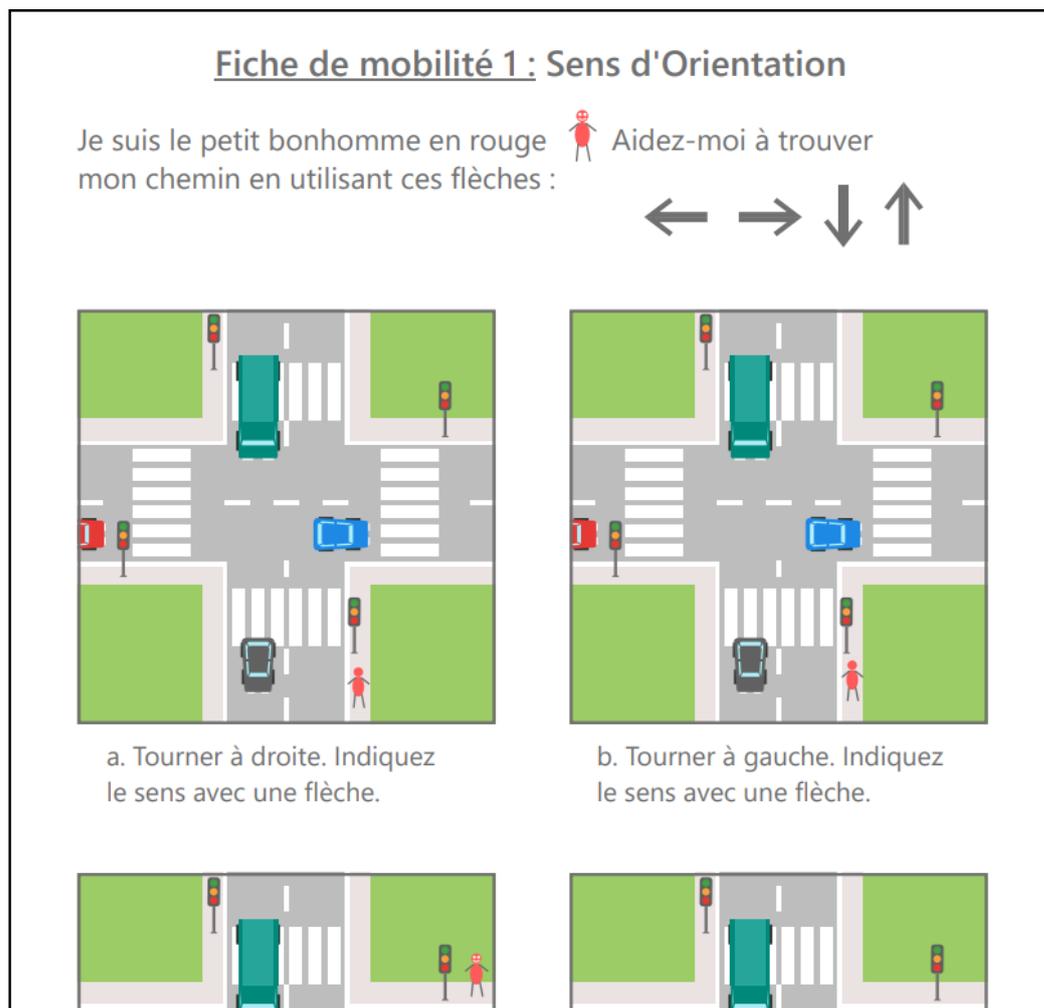


Fig. 6.4 Preview of the navigation worksheet

6.2.2 Co-design workshops

These workshops were designed in order to acquire inputs from young children and trainers. Their participation is important to the design process of the navigation system. Two main workshops were organised:

1. **Navigation worksheet design:** A co-design workshop involved two trainers, three children and the research team. This workshop helped to discuss and agree on best understandable ways to define instructions and design the worksheet study scenarios (cf. Figure 6.4). It started with discussing the understanding of the first draft of this worksheet (cf. Figure 6.5). Figure 6.6 represents a picture taken during the workshop showing a participant explaining their understanding by drawing a navigation path.

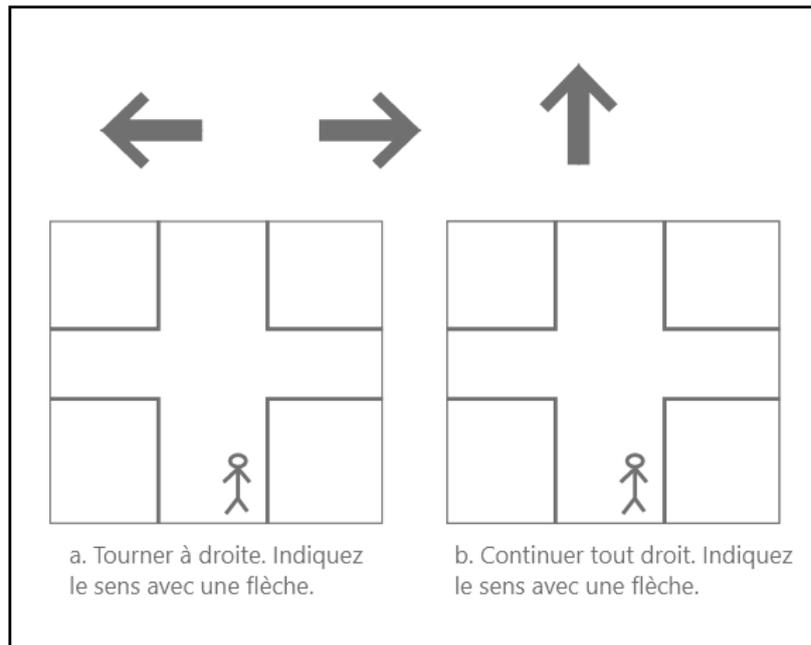


Fig. 6.5 First draft of the navigation worksheet

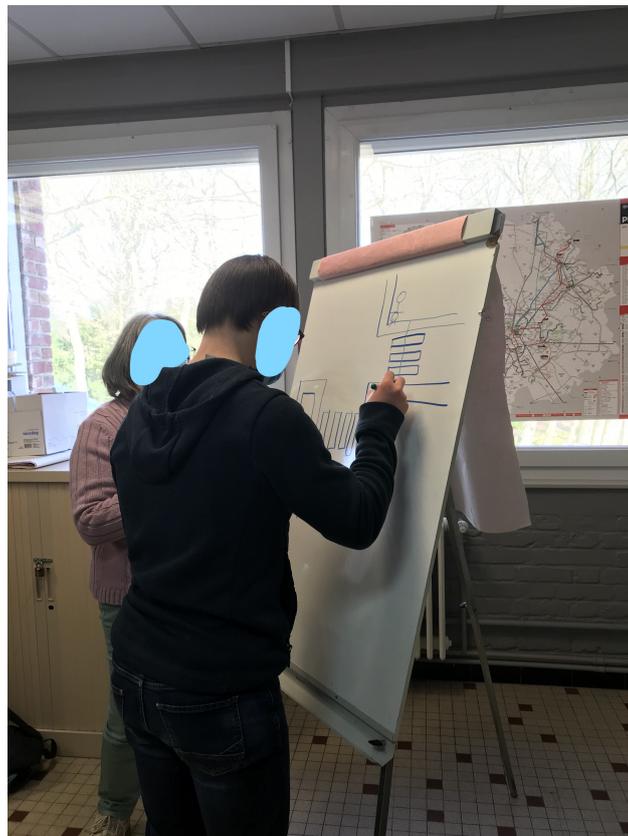


Fig. 6.6 Workshop of the navigation worksheet

Pedestrian Navigation Assistance for People with ID using AR Glasses

The goal of this worksheet was to give many navigation scenarios including road crossing. The participant should plot a path that connects their current position (displayed on the map using an image of a pedestrian) to the destination (explained in the instructions or displayed with a red circle).

2. **Navigation instructions design for AR glasses:** This workshop consisted of presenting different possibilities to display navigation instructions on AR glasses (textual messages were not considered because not all participants were able to read). Then, with the help of the participants (children and trainers), the display could be adapted in order to remove any remaining confusion or misleading information. Figure 6.7 illustrates the different pictograms for the navigation instructions.

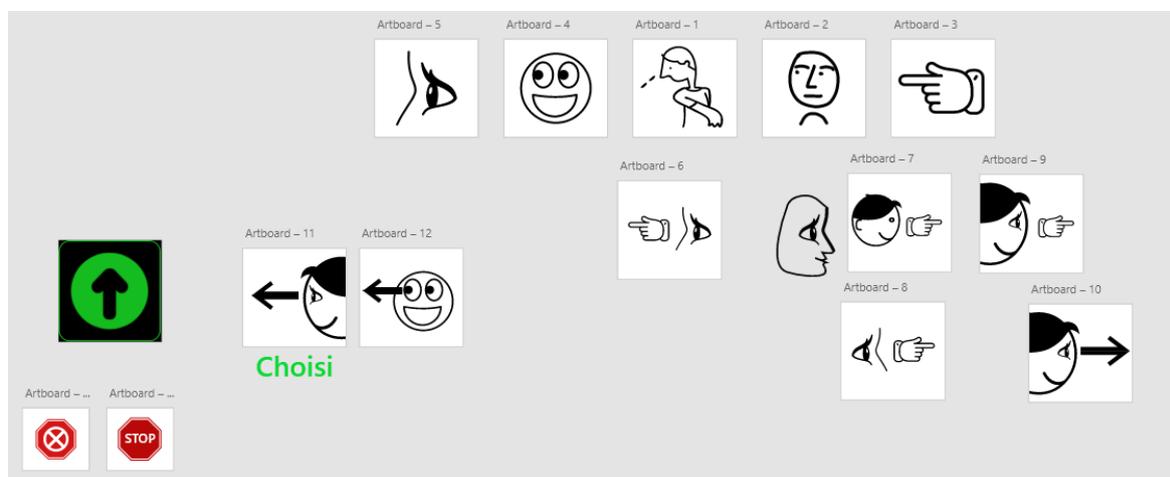


Fig. 6.7 Pictograms designed during the navigation workshop

6.2.3 Field studies

Two field studies were designed in order to assess the usability of the designed system in both use cases: road crossing and path following. Initially, the research team was planning just for the second study (path following). Since the professionals raised the safety concerns while crossing a road, an activity was designed to address this topic.

1. **Road crossing:** it consisted of using the AR glasses in a road crossing scenario inside the institution. Participants were asked to follow the instructions given by the device to perform the task. Figure 6.8 allows to see the location of the road crossing exercise within the IMPRO.



Fig. 6.8 Road crossing - inside the IMPRO

2. **Path following in the city:** it represented a real-life scenario after leaving the institution and walking to a specific destination. Each participant was asked to follow the instructions given by the device, like the first study. Figure 6.9 represents a picture taken during the navigation task in an outdoor environment (public street). It shows how the participant was followed by a research assistant and a professional simulating usual pedestrians as a safety precaution.



Fig. 6.9 Picture of one participant while performing the navigation task - outside the IMPRO

6.3 System Design

The navigation aid system was designed based on the findings of the previous study (Chapter 5). Therefore, the AR glasses are selected as a user interface for this navigation assistance. This section reminds with the designed system for neurotypical users, and it explains how this system was adapted during participatory workshops.

6.3.1 Initial design

Figure 6.10 illustrates the display area of the AR glasses. It is important to consider the dimensions during the design process. The Figure 6.11 represents the first designed system. The instructions displayed are seen through the green rectangle in Figure 6.10.

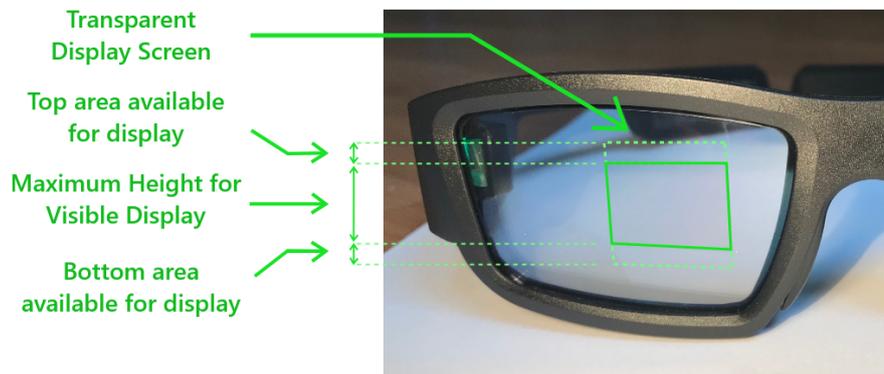


Fig. 6.10 Precise view of the display on the AR Glasses

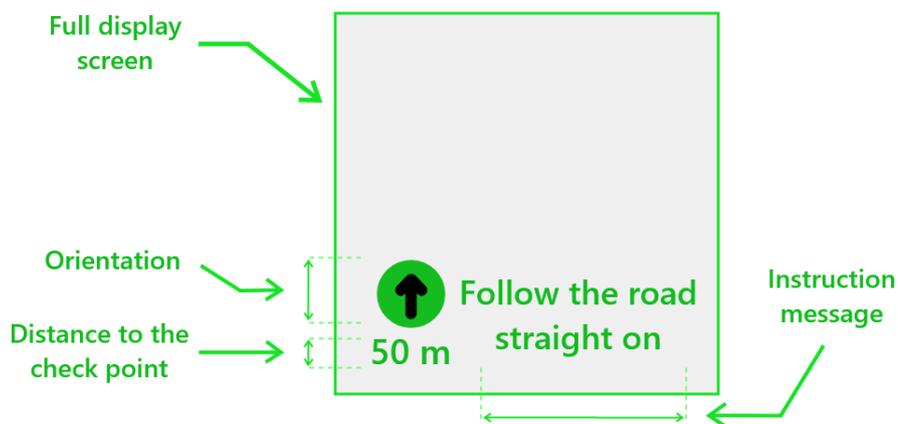


Fig. 6.11 Content design of the initial system design

6.3.2 Co-design workshop

As mentioned earlier in the methodology (Section 6.2.2), this workshop offered the possibility to the participants to personalise the instruction message using visual elements (pictograms). During this session, the 3 participants were asked to explain the interpretation of the suggested pictograms (cf. Figure 6.7). Then, they started to draw their own pictogram based on the discussion they had.

The Figure 6.12 illustrates three suggestions made by the young participants during the participatory workshop. They were asked to draw a pictogram or image of the instruction "Look to the right". These drawings show explicitly how the concepts "eyes" and "arrows" were combined in order to deliver the message. The final design was based on all these findings (cf. next sub-section).



Fig. 6.12 Drawings suggested by the participants (extract)

6.3.3 Final design with multimodal interface

The final design involved six pictograms to illustrate different instructions (cf Figure 6.13). The system was tested during the road crossing study by including two other modalities: audio message and vibro-tactile feedback. Participants were testing combinations like: with or without audio message, and with or without vibro-tactile feedback.

The audio message reads the instructions. The vibro-tactile feedback helps to capture the user attention before displaying the instructions. At the end of this testing, the participants³ agreed on the choice of the three modes combined: visual pictograms, audio messages

³The group's characteristics are mentioned in the next sub-section

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and vibro-tactile feedback. Specific adaptation was considered while designing the audio messages. For example, the system could tell the user "Turn left and cross on the zebra crossing" or "If the road is free, cross the road" (these instructions were given in French during the testing scenario).

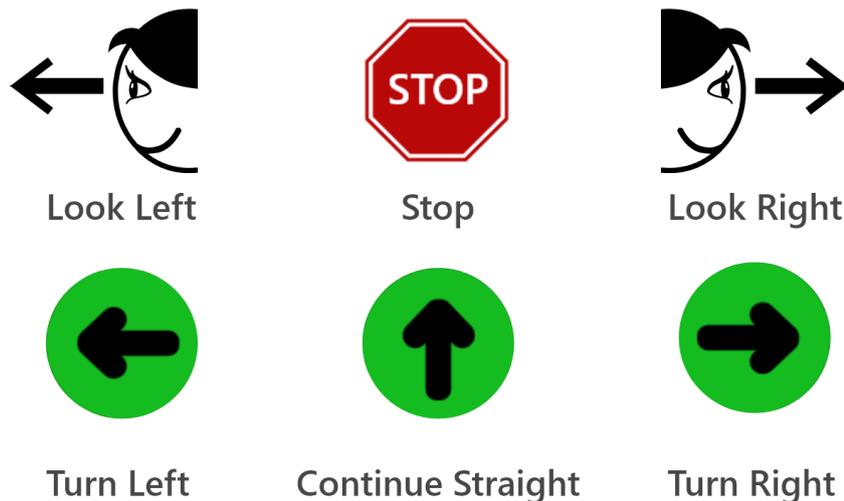


Fig. 6.13 Final pictograms designed for the navigation system

6.4 Study Design

After numerous discussions with the institution's professionals, the road crossing was considered as a major navigation task. A major aspect of safety on the road relies on performing a safe road crossing. The first study has considered this task and has offered few scenarios when participants are asked to use the system while crossing. The second study addressed the navigation to a specific destination in the city. Before performing both tasks, all the participants were asked to fill out a consent (cf. Appendixes E, F and G).

6.4.1 Road Crossing

a. Participants

7 children took part of the study. They have different profile with a set of abilities that could differ from readers to non-readers and also various levels of orientation (2 out of 7 were confusing left and right directions). One child presented a specific case when he was not

aware of his left side. Thus, he tends to ignore upcoming vehicles from the left side. For the lack of time and resources, no further initiatives could have been done in order to assess their navigation skills on a standard scale as the SBSDS (used in the previous study – See Chapter 5).

b. Process

The final version of the system design was used during this step. The multi-modality options were combined and tested following a random order. Three system designs were considered:

1. Visual instructions only (pictograms)
2. Visual instructions with audio messages
3. Visual instructions, with audio messages and vibro-tactile feedback

The testing of the road crossing task was held inside the IMPRO private space (cf. Figure 6.14). Each participant was asked to place themselves on the side of the zebra crossing. When the researcher gives a go-signal, the participant starts the navigation system by using a touch gesture on the glasses' side. The system displays the following instructions (English translation) to guide the user through road crossing task: (1) stop, (2) Look to the left, (3) Look to the right, (4) Look to the left and (5) If the road is free, cross on the zebra crossing.

In order to make the experience more realistic and safe, the road traffic was mimicked by including an actor using a bicycle. This actor was trying to come at key moments when the participant tried to cross or in the middle of the road. The pedestrian was given high priority but their reactions were observed.



Fig. 6.14 Zebra crossing inside the IMPRO

6.4.2 Path Following

In this phase, the designed system was put in real-life scenario testing. The main goal was to observe and assess the usability of the system. Participants were asked to use the AR glasses and follow the instructions provided to reach an unrevealed destination.

Participants

5 participants (16 to 21 years old) were invited to this study. Similarly to the road crossing testing, participants have different levels of intellectual capabilities. It ranges from a good level of independence to not being aware of one body's side. The selection of these participants was based on two main factors: (1) diversifying the level of independence in outdoor environment and (2) safety. For both factors, the professionals helped to make this decision based on their work experience with different participants.

Path definition and navigation instructions

In order to define the study's path, the researcher suggested two possible itineraries starting from the main door of the IMPRO to (1) the gym, where the children are going for different sport activities but taking a different route, (2) to the city hall. The second path was considered for the study after discussing with the professionals. Figure 6.15 illustrates the defined path with different navigation instructions. During the design of this path, the road crossing task was included for two zebra crossing as shown in the same figure.

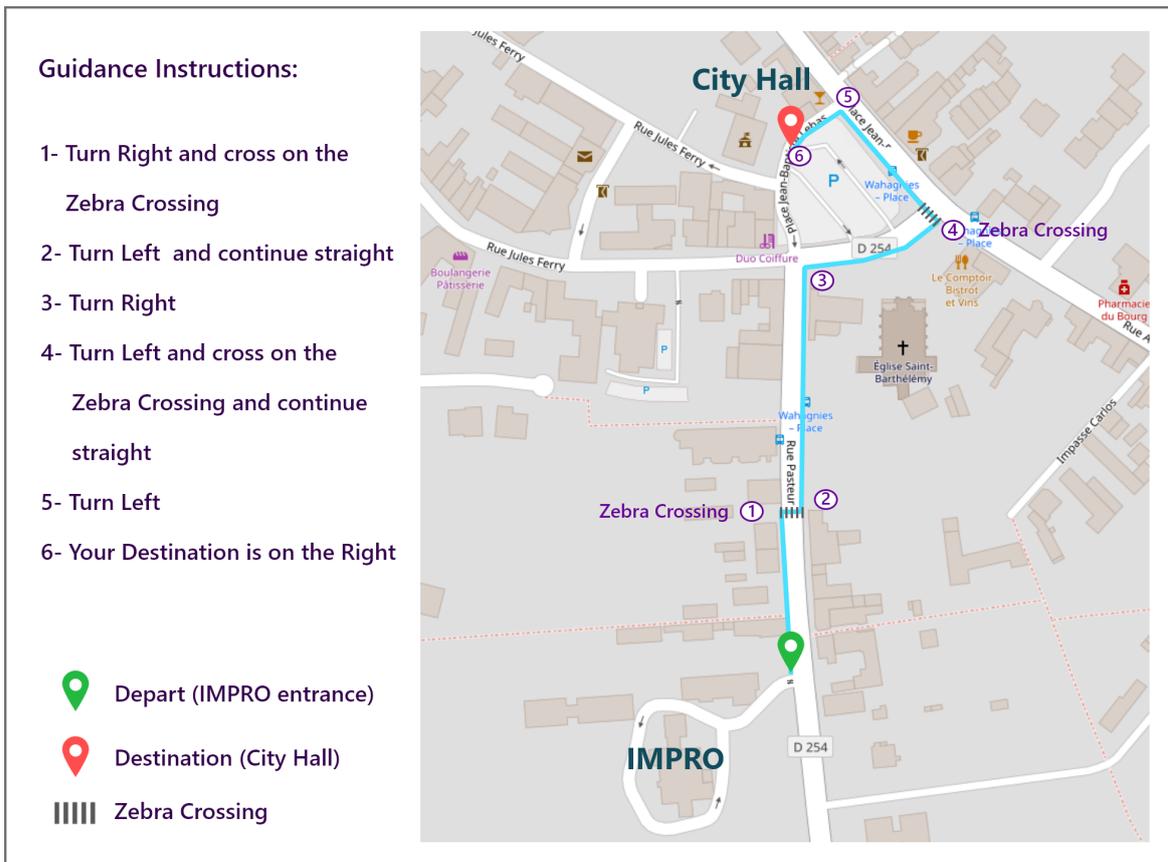


Fig. 6.15 Study’s path highlighting different navigation instructions

Usability testing

A qualitative testing was included. It helped to gather the participants thoughts and feedback about the system. This testing consists of an adapted SUS (System Usability Scale). It was adapted using 5 emojis (cf. Figure 6.16) in order to make it easier to pick an evaluation for each question. To clarify the participants thoughts for different evaluations, an interview was accompanying the response to the questionnaire.



Fig. 6.16 SUS scale using 5 emojis

6.5 Results

6.5.1 Road Crossing Study

In this study, the usability testing was performed as a qualitative evaluation. The first goal of this evaluation was to assess any difficulties affecting the use of the system. As a second goal, the safety factor was considered during the road crossing task.

The chart below, in Figure 6.17, shows the different usability scores given by the 7 participants. The overall experience seems to be satisfying (an average usability score of 72.14%). It shows also that participant 1 (P1) gave the lowest score (40%) for the usability of the system. The semi-formal interviews allow to explain this dissatisfaction. They explain P1 pointed out an inconsistency in the system due to a personal difficulty to identify the correct side, left or right. From the success rate task, 7/7 participants performed the road crossing task safely.

Figure 6.18 gives a detailed view of the evaluation given to each question of the SUS questionnaire.

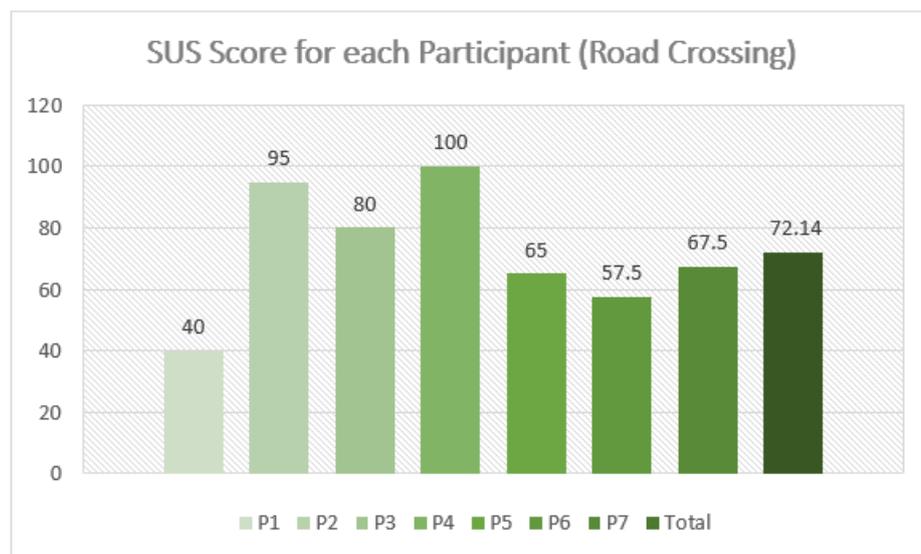


Fig. 6.17 Global SUS score of the 7 participants

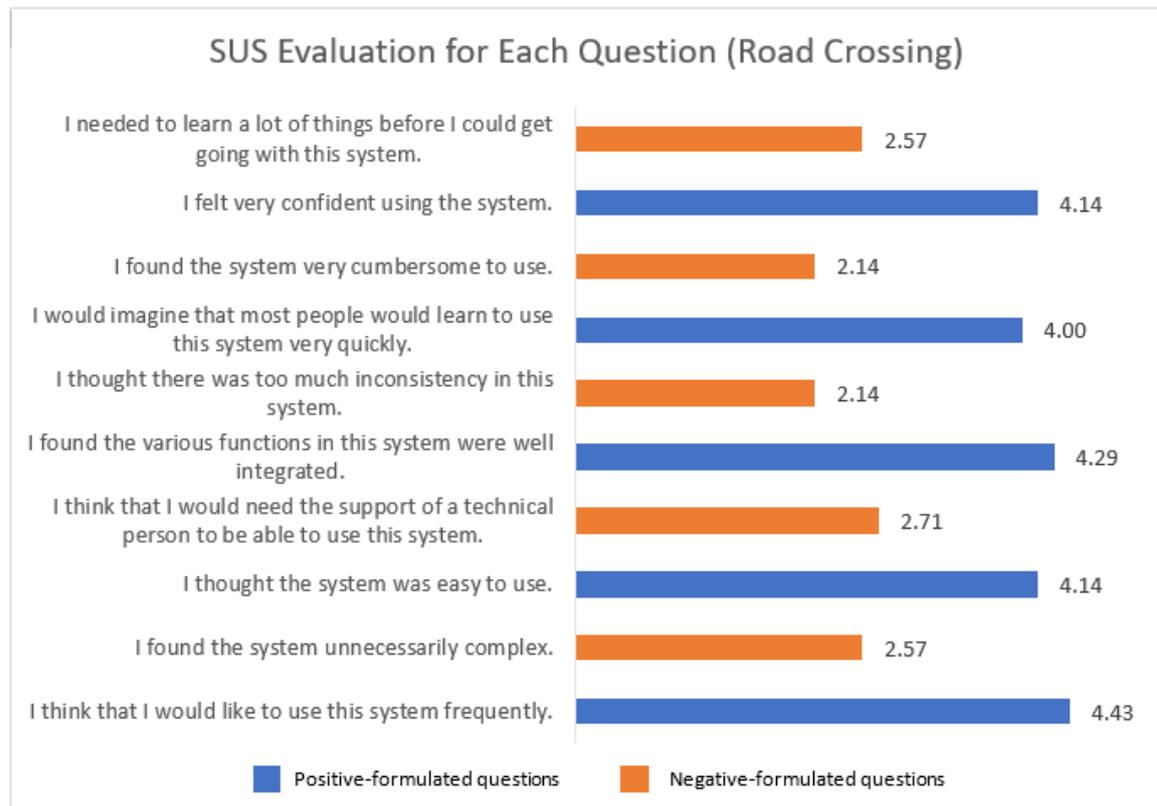


Fig. 6.18 Detailed SUS evaluation for each question (average score)

6.5.2 Path Following Study

The chart below, in Figure 6.19, shows the different usability scores given by the 5 participants. The overall experience seems to be satisfying (an average usability score of 88.50%).

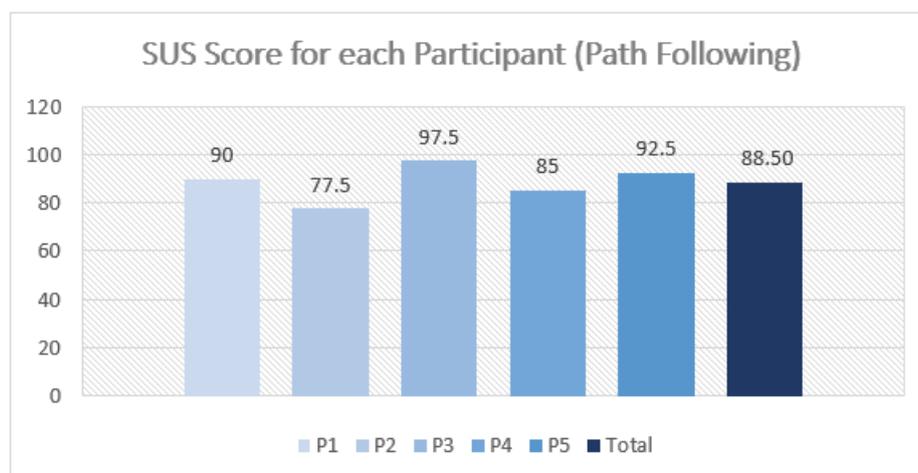


Fig. 6.19 Global SUS score of the 5 participants

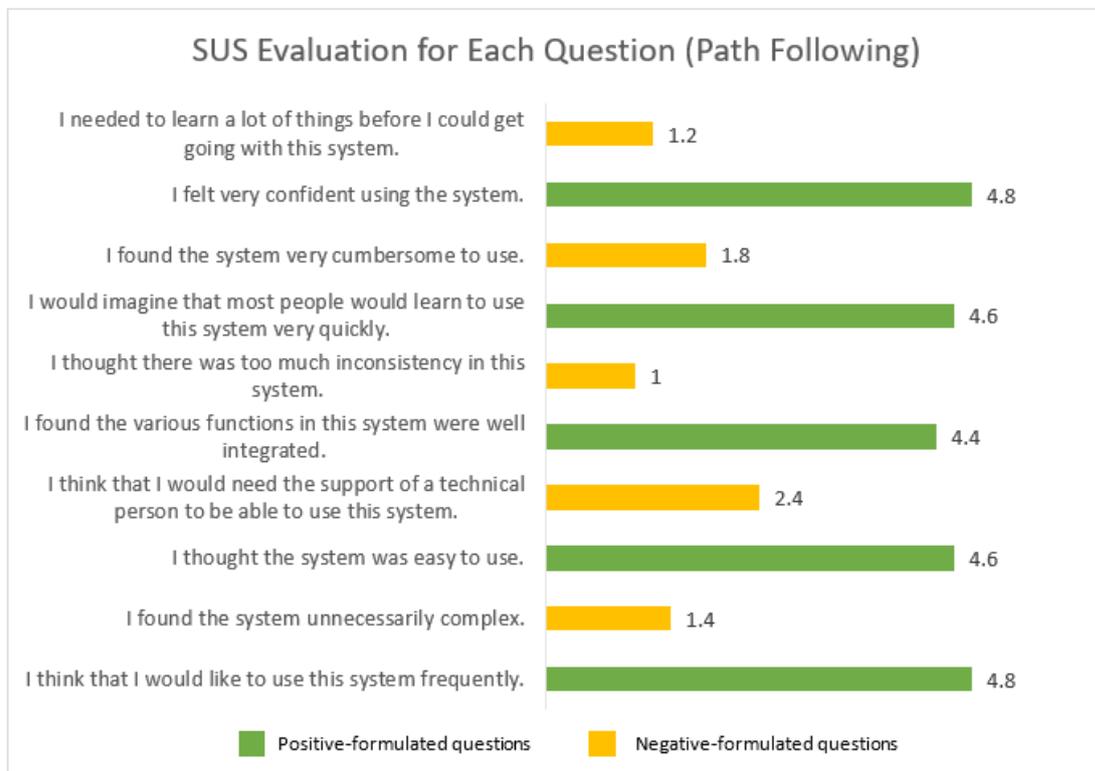


Fig. 6.20 Detailed SUS evaluation for each question (average score)

The success rate of the navigation task could be assessed as 100% where all the five participants reached the destination without a particular difficulty. One participant, who was not aware of their left side, was tempting to cross on a bus stop (yellow lines) after ignoring the zebra crossing. The explanation given in this context by the participant put the light on the timing of the received instruction (number 1, cf. Figure 6.15). For them, it did not give enough time to process it and to make the right decision.

Figure 6.20 gives a detailed view of the evaluation given to each question of the SUS questionnaire.

6.5.3 Final Feedback Session

This session gathered all the participants in both studies and the different activities and workshops held at the IMPRO. It involved also their trainers and administration staff. This feedback session consisted of presenting the different activities, already presented along the sections of this chapter, and gave the chance to the attendees to give comments and explain how they felt about each step in the research process and the overall experience. At the end, three questions were asked in order to evaluate their satisfaction:

1. Did you like this experience working together?
2. If you will be given these AR glasses, would you be using them on a daily basis?
3. Do you think that these glasses would help you to know better your environment?



Fig. 6.21 Answers for the first question during the final feedback session

To make the experience easier, the attendees were asked to draw a happy or sad face for a yes and no answer respectively (cf. Figure 6.21). The different attendees agreed on giving a "YES" answer for the three questions which could be translated into a high satisfaction about the entire collaboration.

6.6 Conclusion

In this chapter, a rich protocol for research was presented and explained throughout different sections. It highlighted a creative approach while building collaborative relationship with the targeted audience and the professionals of the IMPRO institution. This section gave details about the activities used such as the user shadowing to understand the children interactions, different navigation exercises to understand their navigation skills and their consideration to the road safety. Then, since the research approach is user-centred, the targeted audience was involved through participatory workshops that aimed to design learning materials (navigation worksheets) and to adapt the AR glasses assistance system by suggesting and creating relevant pictograms. The final step consisted of two field studies. The first one was about the task of

Pedestrian Navigation Assistance for People with ID using AR Glasses

road crossing and how the system should put the safety of the users first. The second study considered navigation aspect in a real-world traffic aiming to reach a specific destination. Both studies shown positive results and promising learning that will be discussed in the next and last chapter. The feedback session at the end helped to gather an evaluation on the overall experience during this rich collaboration which was so far satisfying for both teams, research and IMPRO.

Chapter 7

Conclusion & Perspectives

The goal of this thesis was to contribute to the design of navigation aid systems for people with ID. Navigation is an indispensable skill that helps to move through the environment and responds to people's needs. This "granted" skill for many people could be a dream for others with diverse levels of difficulties including aging impact and disability. ValMobile project aimed to address the needs of people with ID by designing a navigation assistance system using AR glasses. The main scope of this research was defined by the question: How could we design an adapted navigation aid system for people with ID?

To begin, the state of art came to present the existing projects in the literature i.e. related work to navigation and people with ID. In this section, the wayfinding taxonomy was presented along with an overview of spatial knowledge acquisition. A comparison was made between different navigation aid systems that existed to support people with different levels of needs. This helped to understand the limitations of the existing solutions and stated the importance of the current approach. The ontology discussion that was included in this section was aiming to prepare for the novel ontology presented in the first chapter of the contribution.

In order to establish a common language to communicate with different stakeholders, chapter III introduced a new ontology addressing the topic of navigation. This chapter described the approach used to create the different concepts related to the navigation. In fact, the novel ontology contributed to build a clear communication between the researchers with different backgrounds (psychology, human-computer interaction, ergonomics, etc.). The validation scenario presented a real life scenario and showed how this ontology could be included in NAS design. These systems could be even extended to be adaptive to the context of navigation. This characteristic could be implemented along with the wayfinding model in mind. This can also consider other models and processes for inspiration as the Perception-Decision-Action (see [44]).

Conclusion & Perspectives

Chapter IV presented the new Wayfinding Model to offer a design-oriented tool to build personalised NAS. It came with a more comprehensive view of different states provided initially in the wayfinding taxonomy by [114]. It described the transitions between different states based on the spatial knowledge of the person in navigation. This chapter enumerated a list of design guidelines that could be considered in the future design and improvements of NAS. The preliminary study has confirmed the usability of the Vuzix AR Glasses while considering one state (path following) of the Wayfinding Model.

Next challenges are to consider more states of wayfinding and discuss detailed user interface design on different platform of interactions. Many studies could be performed to consider progressively all wayfinding states and transitions present on this model, as in [57].

Other perspectives could be focused on the human beings and in particular on people with special needs (due to disabilities, age, etc.). Indeed, navigation systems could be enriched with finer models, allowing for more personalized interaction and user-tailored interfaces for instance for people with intellectual disabilities [5, 61]. More generally, this approach may contribute to one of the grand challenges of HCI, particularly accessibility and universal access [17]. Furthermore, with a transport multi-modality vision, this work could be extended to facilitate the coupling of transport modes to the pedestrian modality.

NAS are widely designed especially for smartphones. One of the motivations behind the contribution in chapter V is to explore more in depth the navigation experience using a smartphone and to compare it to the AR glasses. This comparison helped to understand the influence of each device on two aspects: navigation performance and spatial knowledge acquisition. This chapter helped to evaluate both devices and choose the AR glasses as a testing platform for people with ID. One of the limitations of the study presented in this chapter is the number of participants. It could be interesting to consider a bigger set of participants over a longer testing periods between the different walk sessions (the current study considered one week between both walk sessions). Future studies could also consider including other navigation support such as smartwatches, audio earpods, vibro-tactile belts, other navigation smartphone apps, etc. Different more or less complex pathways may be envisaged, including different categories of landmarks to use and memorize.

The last chapter of the contribution section represents the result of more than three years of exploring, thinking, designing and testing. It was the ultimate goal to include the users in the design process since the beginning. The pandemic conditions and the depth of the required research beforehand made it difficult to include the users (people with ID) almost in the first two years. However, the waiting time paid off at the end. This chapter demonstrated the depth of the research protocol which included: users shadowing during their weekly transport workshops, connecting and building a trustful collaborative relationship,

leading co-design workshops, real-life scenario testing and at the end, a final feedback and communication session. The output of the co-design workshops consisted of an adapted UI for the AR Glasses. It was proved its usability and relevance to targeted audience.

As a closing note, this research intended to make life better for people with ID. It aimed to support their independence during daily navigation tasks. The best success metric to evaluate this PhD work is to have a testimonial by the users. In the final feedback session, at the IMPRO with all the young participants and their trainers, one participant (21 years old with ID) said in French: "Je vais utiliser ces lunettes et pas Google maps sur mon téléphone, au moins elles sont devant nos yeux et on n'a pas besoin de regarder en bas. Si on regarde tout le temps le téléphone, on ne peut pas regarder la route. Elles vont servir plutôt à aller dans des endroits inconnus". The English translation is: "I rather choose to use these AR Glasses than my smartphone with Google Maps. At least, these glasses are in front of my eyes and wouldn't need to look down. If I look all the time at my smartphone, I won't be able to see the street. They will serve when I go to unfamiliar places.". This participant highlighted the importance of being focused on the road for safety reasons, and to use a navigation aid system when moving through an unfamiliar environment as a learning process. These findings are intended to be one step towards mobility independence of people with ID for their daily life. The ultimate goal would be to support them to develop navigation skills and learn their environment in order to be autonomous and independent from any assistance.

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Appendices

Appendix A

Detailed Ontology on Pedestrian Navigation (In French)

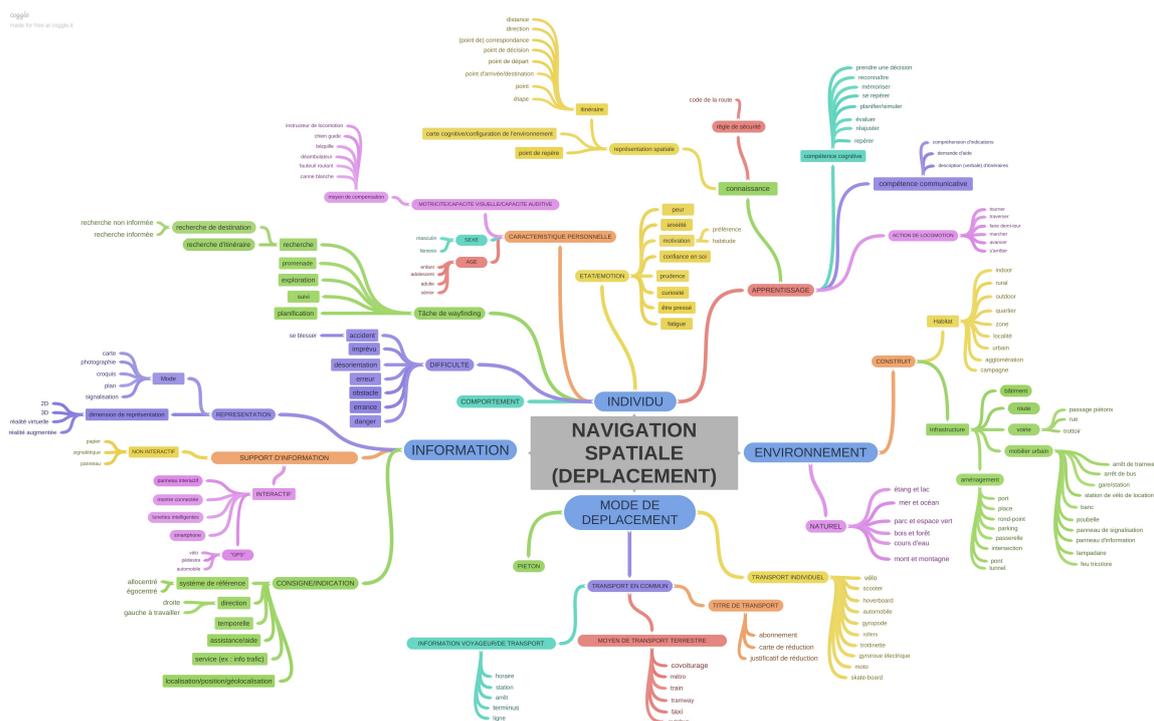


Fig. A.1 Detailed Ontology on Pedestrian Navigation

Detailed Ontology on Pedestrian Navigation (In French)

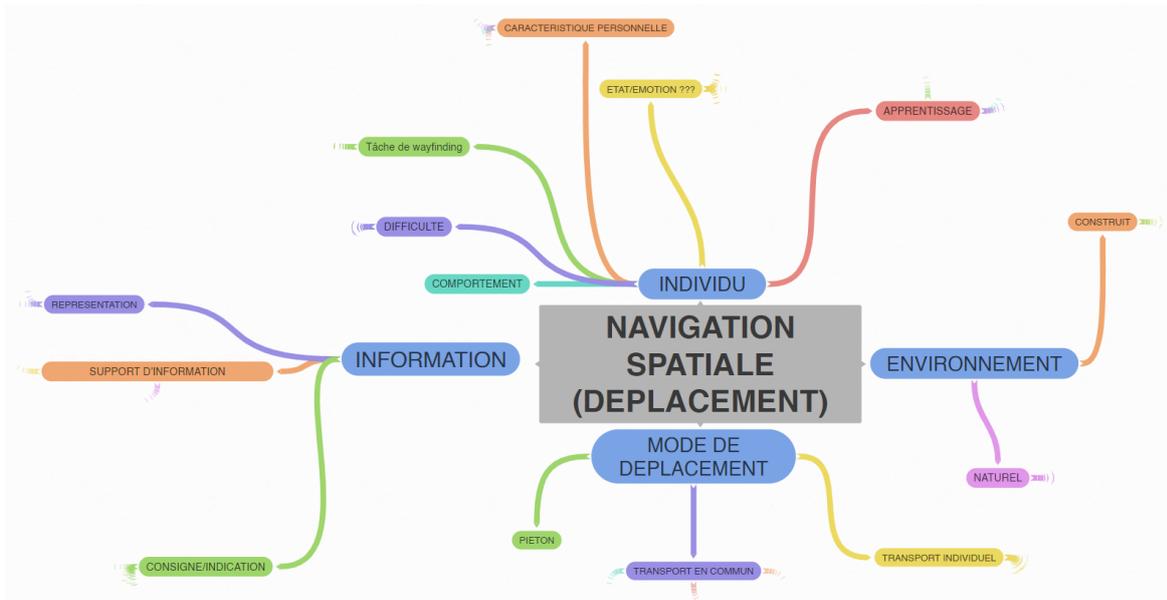


Fig. A.2 Main concepts of the ontology

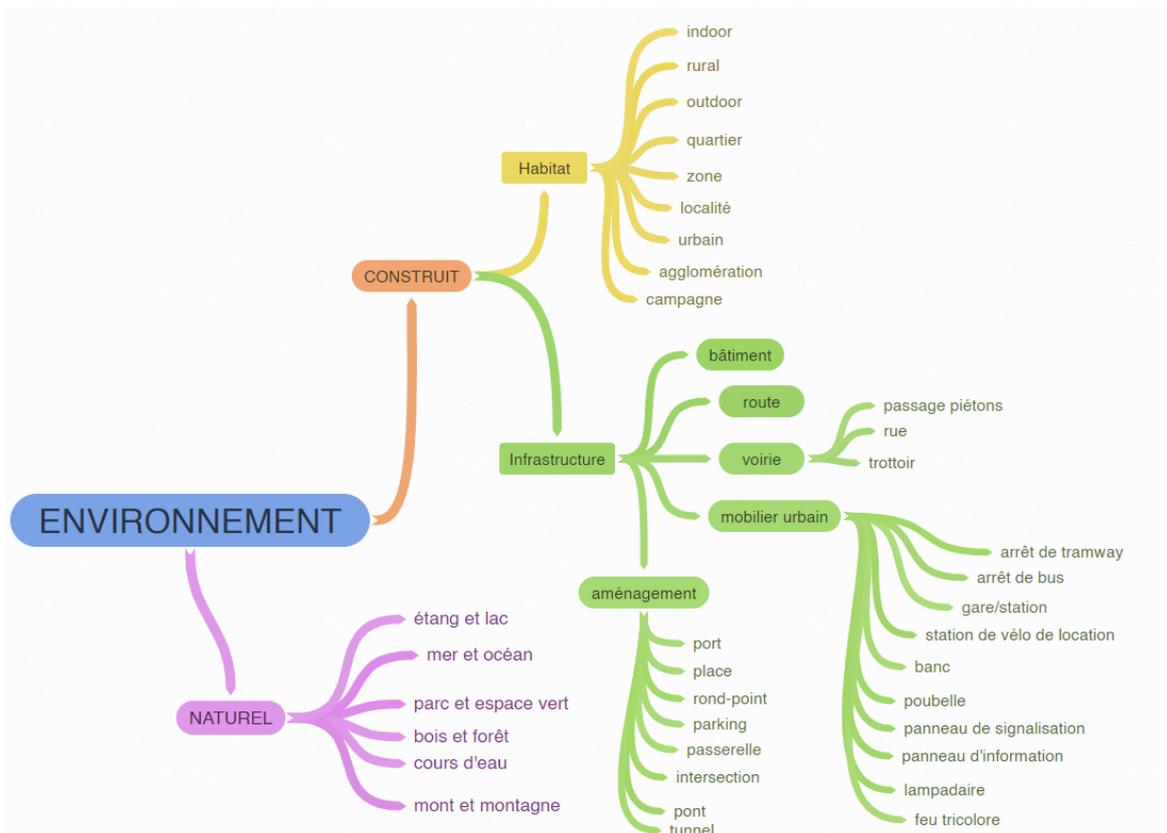


Fig. A.3 Sub-concepts of Environment (Ontology)

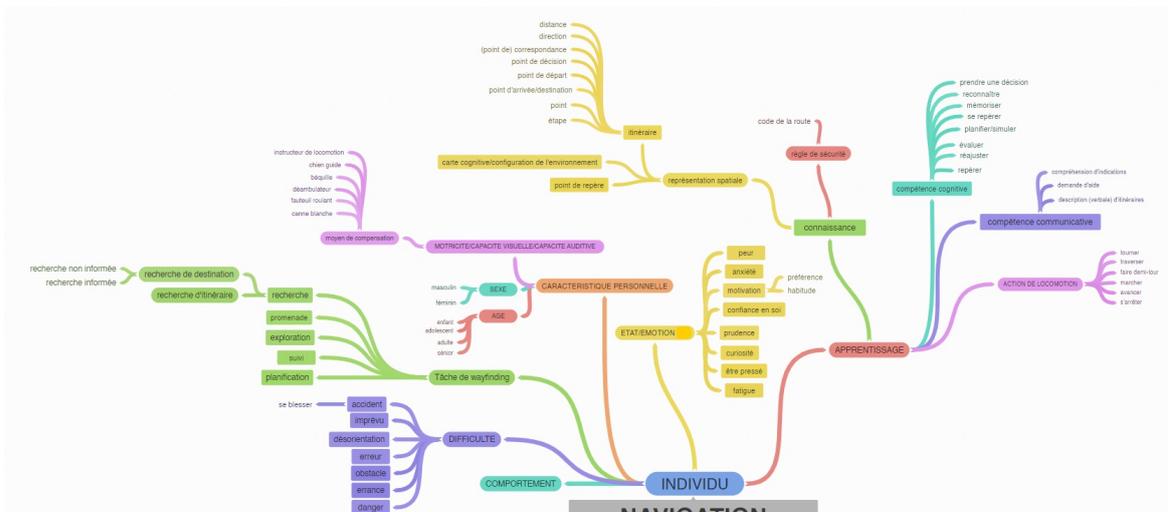


Fig. A.4 Sub-concepts of Person (Ontology)

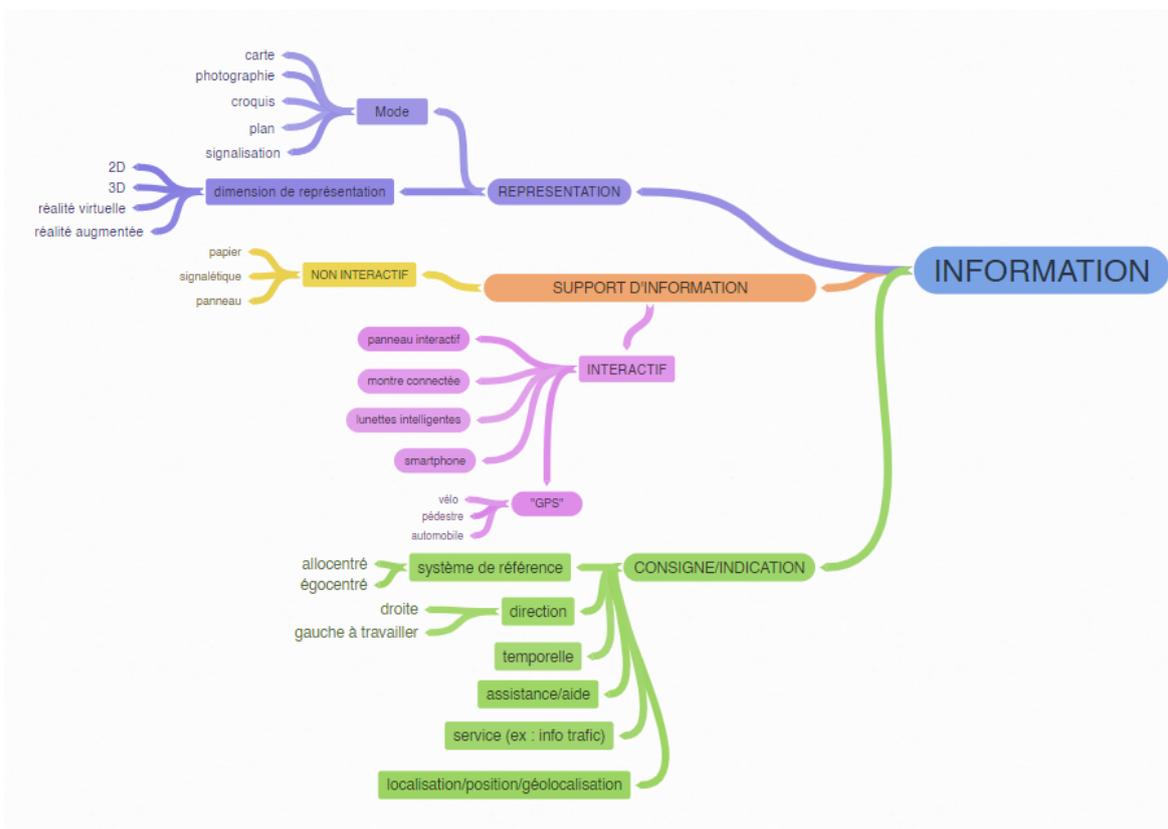


Fig. A.5 Sub-concepts of Information (Ontology)

Detailed Ontology on Pedestrian Navigation (In French)

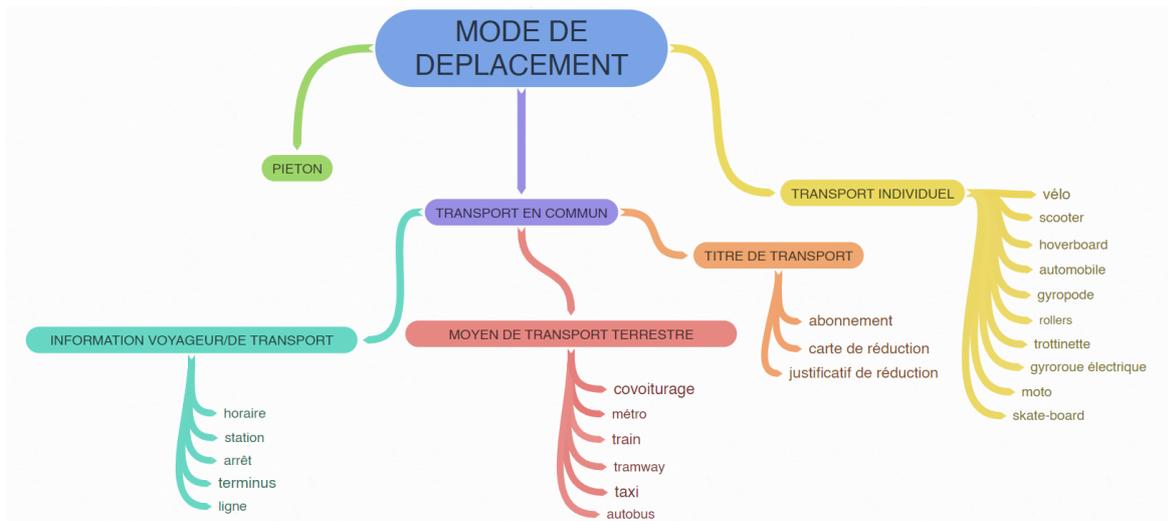


Fig. A.6 Sub-concepts of Transport modes (Ontology)

Appendix B

Experiment Questionnaire for the Preliminary Study (In French)

Experiment Questionnaire for the Preliminary Study (In French)

Fiche d'expérimentation : Lunettes AR pour le guidage

Participant N° :

Durée du parcours ALLER (mns):

Durée du parcours RETOUR (mns):

I. Consigne :

1. L'objectif est d'utiliser des lunettes électroniques de réalité augmentée (AR) pour atteindre une destination inconnue au départ.
2. Vous aurez la possibilité de tester les lunettes avant le départ :
 - a. Afficher les messages de navigation.
 - b. Naviguer entre les applications installées sur les lunettes.
3. Le test des lunettes permet de vérifier la visibilité de l'affichage sur les lunettes.
4. Vous recevrez des directives progressivement indiquant la distance en mètre, des points de repère qui servaient pour savoir quand il faudrait tourner par exemple.
5. Les participants sont amenés à passer par des points de repère (comme des checkpoints) pour valider le parcours.
6. Un bouton est mis à votre disposition sur l'application mobile pour valider le passage près d'un point de repère en cas de besoin.

II. Questionnaire : Profil participant

Question	Oui	Non	Réponse ouverte / commentaire
Avez-vous déjà utilisé un dispositif de réalité augmentée ?			
Est-ce que vous avez déjà utilisé des lunettes électroniques de réalité augmentée ?			
Pour vos déplacements en tant que piéton, utilisez-vous une application de GPS ? Si oui laquelle ?			
Pour vos déplacements en voiture, utilisez-vous une application de GPS ? Si oui laquelle ?			
Avez-vous une correction aux yeux ? Si oui, laquelle ?			

Fig. B.1 Experiment questionnaire (page 1)

Fiche d'expérimentation : Lunettes AR pour le guidage

Participant N° :

Expérience globale : Selon quel degré êtes-vous d'accord avec les propos ci-dessous ?

1 : pas du tout d'accord

5 : Tout à fait d'accord

Question	1	2	3	4	5	Commentaire
Les informations affichées sur les lunettes sont lisibles.						
Les lunettes permettent de se concentrer sur l'environnement extérieur.						
Les points de repère permettent de mieux comprendre les directives de guidage.						
Le chemin de retour était facile grâce aux informations fournies au départ par les lunettes.						
Les points de repère indiqués fournis numériquement correspondaient bien aux points de repère réels.						
Les applications de GPS sont indispensables pour vos déplacements à pieds dans votre ville.						
Les lunettes de Réalité augmentée pourraient faciliter les déplacements piétons.						
Les messages affichés sur les lunettes sont perturbants et ne permettent pas de rester concentré sur l'environnement.						
Je préfère utiliser une application mobile à la place de ces lunettes AR.						
Une lecture audio des messages pourrait faciliter la réception des informations.						
Pour m'orienter durant mes trajets, j'utilise des points de repères très souvent. - Pouvez-vous nous donner des exemples de points de repère ?						
Les points de repère facilitent le suivi de chemin.						

Fig. B.2 Experiment questionnaire (page 2)

Experiment Questionnaire for the Preliminary Study (In French)

Fiche d'évaluation SUS : Lunettes AR pour le guidage

Participant N° :

	Pas du tout d'accord				Tout à fait d'accord
1. Je pense que je vais utiliser ces lunettes AR fréquemment	<input type="checkbox"/>				
	1	2	3	4	5
2. Je trouve ces lunettes AR inutilement complexe	<input type="checkbox"/>				
	1	2	3	4	5
3. Je pense que ces lunettes de réalité augmentée (AR) sont faciles à utiliser	<input type="checkbox"/>				
	1	2	3	4	5
4. Je pense que j'aurai besoin de l'aide d'un technicien pour être capable d'utiliser ces lunettes AR	<input type="checkbox"/>				
	1	2	3	4	5
5. J'ai trouvé que les différentes fonctions de ces lunettes AR ont été bien intégrées	<input type="checkbox"/>				
	1	2	3	4	5
6. Je pense qu'il y a trop d'incohérence dans ces lunettes AR.	<input type="checkbox"/>				
	1	2	3	4	5
7. J'imagine que la plupart des gens serait capable d'apprendre à utiliser ces lunettes AR très rapidement.	<input type="checkbox"/>				
	1	2	3	4	5
8. J'ai trouvé ces lunettes AR très lourdes à utiliser.	<input type="checkbox"/>				
	1	2	3	4	5
9. Je me sentais très en confiance en utilisant ces lunettes AR.	<input type="checkbox"/>				
	1	2	3	4	5
10. J'ai besoin d'apprendre beaucoup de choses avant de pouvoir utiliser ces lunettes AR.	<input type="checkbox"/>				
	1	2	3	4	5

Fig. B.3 Experiment questionnaire - SUS (adapted from [39, 11, 16]) (page 3)

Appendix C

Questionnaire: Exploring Area's Landmarks

In the area illustrated in the map bellow, we aim to identify relevant landmarks which could be used to give assistance for people navigating this area. Feel free to answer the following questions based on your own experience.

I. Before we start:

- Are you: Male? Female?
- How old are you?
- How long were you living in this area?

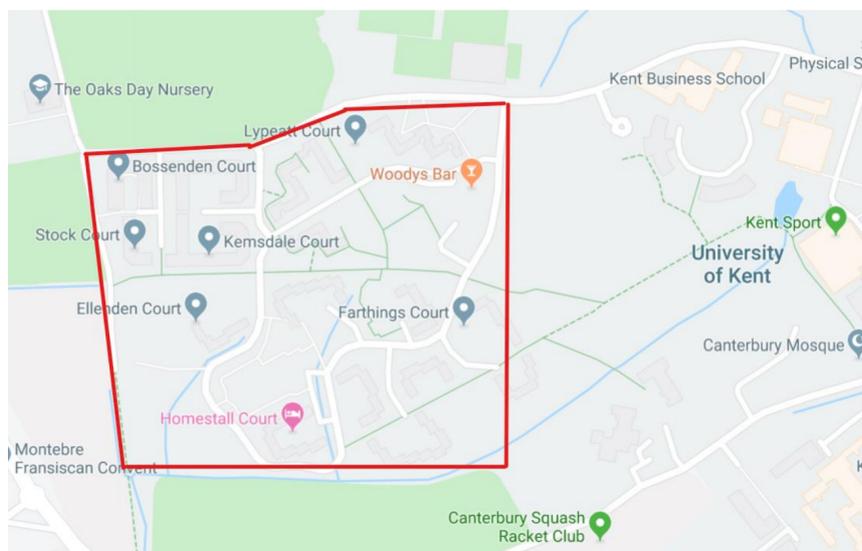


Fig. C.1 Study area

Questionnaire: Exploring Area's Landmarks

II. Here we go!

In this section, we suggest three maps. Enjoy marking what could be relevant landmarks. Imagine yourself in the situation below: - A new people to this area were asking you for guidance, what are the landmarks would you use to guide them?

1. An empty map:

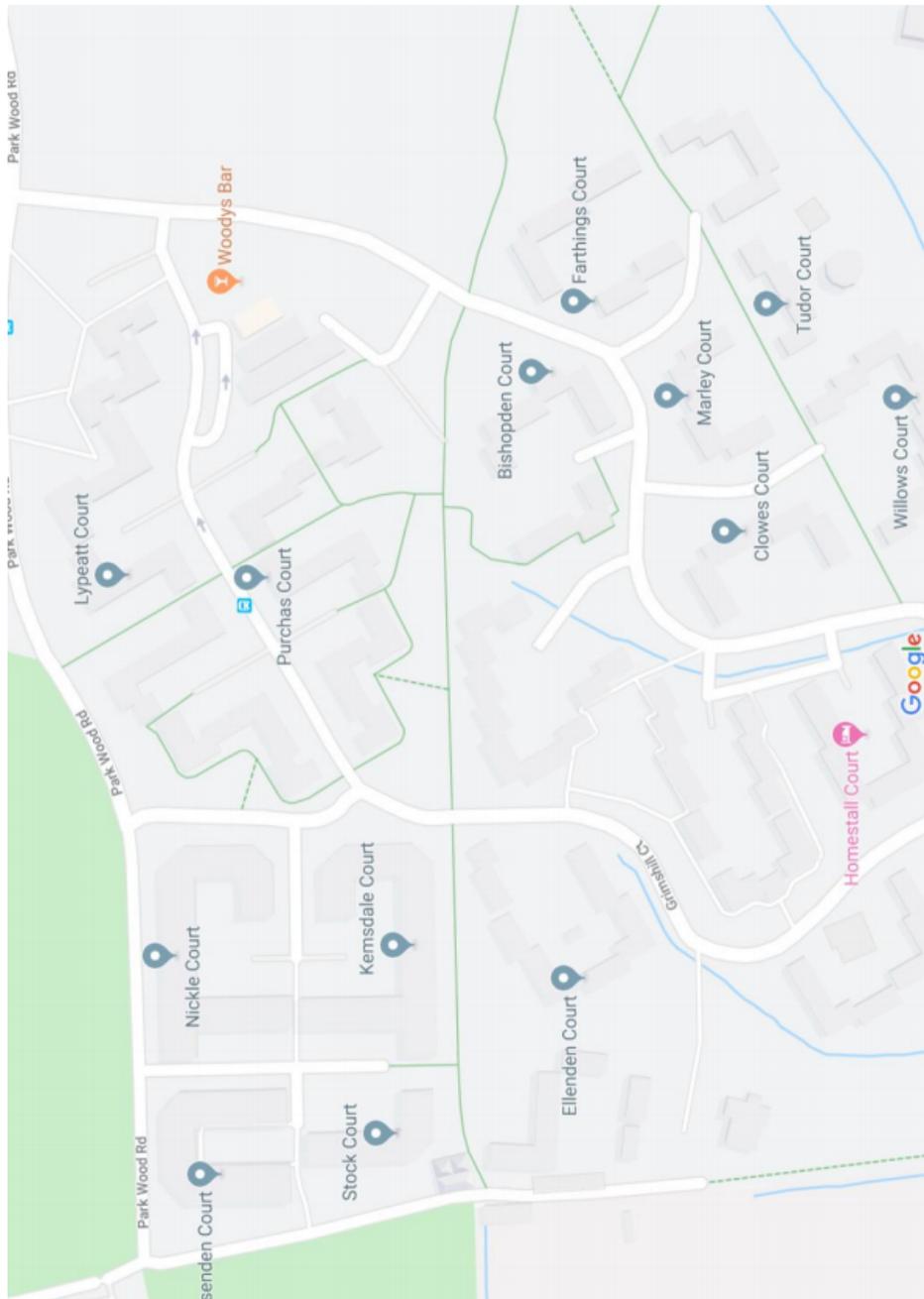


Fig. C.2 Empty map of the study area to highlight relevant landmarks

Questionnaire: Exploring Area's Landmarks

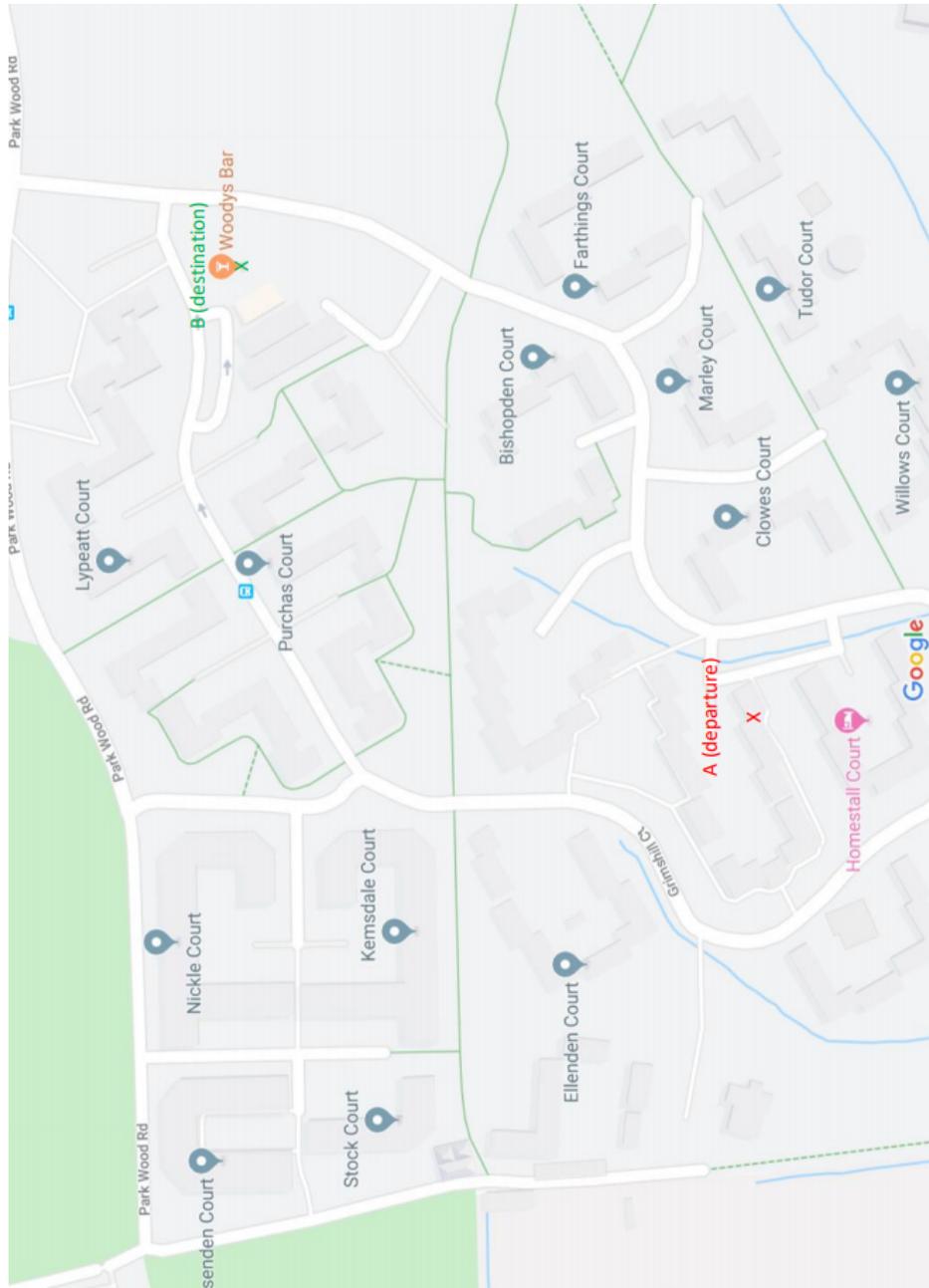


Fig. C.4 Empty map with a second proposition of A&B points

Appendix D

Memory Test using a printed map



Fig. D.1 Printed Map for Memory Testing

Appendix E

Declaration of Consent: IMPRO indoor Study - Road Crossing

Documents
d'informations et
formulaire de
consentement



Fig. E.1 Consent for in-door testing: Road Crossing (page 1)

Accord de participation au projet « ValMobile »



■ **Le projet « ValMobile » c'est quoi ?**

Le projet permettra de faire des activités pour :

- Faciliter mon déplacement ;
- Apprendre à traverser en sécurité ;

Si je veux participer au projet, je dois :

1. Utiliser des outils technologique (lunettes de réalité augmentée, téléphone ou casque audio)
2. Suivre les instructions fournies par cette technologie pour traverser une route à l'intérieur de l'IMPRO.

Est-ce que quelqu'un connaîtra les informations que je donne sur moi ?

- Mes réponses ne seront pas données aux éducateurs, aux professionnels, aux médecins ou à ma famille.
- Personne ne saura que c'est moi qui ai répondu. Mon nom n'est pas écrit sur le questionnaire.
- Mes réponses seront seulement utilisées pour le projet.



Est-ce que je suis obligé de participer ?

- Je peux participer au projet « ValMobile » si j'ai envie.
- MAIS si je veux participer, je dois participer à une étude de déplacement et de traversée de route à l'intérieur de l'IMPRO.
- J'accepte de répondre à des questions.
- J'accepte d'être pris en photo à condition que mon visage soit flouté.
- Je peux arrêter quand je veux.

Fig. E.2 Consent for in-door testing: Road Crossing (page 2)

**Je peux poser toutes les questions que je veux.
Si j'ai un problème, je peux le dire, quelqu'un m'écouterà.
Je peux demander à Isabelle BAYART.**

Je donne mon accord

J'entoure la réponse



Moi		
Je suis d'accord pour faire les entretiens	Oui	Non

Date _____

Ma signature :

Signature de la personne qui mène l'étude :

Signature de mon tuteur (Uniquement si je suis sous tutelle) :



Fig. E.3 Consent for in-door testing: Road Crossing (page 3)

Appendix F

Declaration of Consent: IMPRO outdoor Study - Path Following

Documents
d'informations et
formulaire de
consentement



Fig. F.1 Consent for outdoor testing: Path Following (page 1)



■ Le projet « ValMobile » c'est quoi ?

Le projet permettra de faire des activités pour :

- Faciliter mon déplacement ;
- Apprendre à se déplacer en sécurité ;

Si je veux participer au projet, je dois :

1. Utiliser des outils technologique (lunettes de réalité augmentée, téléphone ou casque audio)
2. Suivre les instructions fournies par cette technologie pour parcourir un itinéraire comme une activité de repérage à côté de l'IMPRO, à Wahagnies.

Est-ce que quelqu'un connaîtra les informations que je donne sur moi ?

- Mes réponses ne seront pas données aux éducateurs, aux professionnels, aux médecins ou à ma famille.
- Personne ne saura que c'est moi qui ai répondu. Mon nom n'est pas écrit sur le questionnaire.
- Mes réponses seront seulement utilisées pour le projet.



Est-ce que je suis obligé de participer ?

- Je peux participer au projet « ValMobile » si j'ai envie.
- MAIS si je veux participer, je dois participer à une étude de déplacement et de traversée de route à l'intérieur de l'IMPRO.
- J'accepte de répondre à des questions.
- J'accepte d'être pris en photo à condition que mon visage soit flouté.

Fig. F.2 Consent for outdoor testing: Path Following (page 2)

Declaration of Consent: IMPRO outdoor Study - Path Following

- Je peux arrêter quand je veux.

**Je peux poser toutes les questions que je veux.
Si j'ai un problème, je peux le dire, quelqu'un m'écouterà.
Je peux demander à Isabelle BAYART.**

Je donne mon accord

J'entoure la réponse



Moi		
Je suis d'accord pour faire les entretiens	Oui	Non

Date _____

Ma signature :

Signature de mes parents :

Signature de la personne qui mène l'étude :

Signature de mon tuteur (Uniquement si je suis sous tutelle) :



Fig. F.3 Consent for outdoor testing: Path Following (page 3)

Appendix G

Declaration of Consent for Personal Picture Usage: IMPRO outdoor Study - Path Following

Declaration of Consent for Personal Picture Usage: IMPRO outdoor Study - Path Following



Les Papillons Blancs du Nord

DEMANDE D'AUTORISATION D'UTILISATION

DE L'IMAGE D'UNE PERSONNE

Événement : Soutenance de thèse et présentation du travail de recherche (article de conférence et journal scientifique)

Personne photographiée ou filmée :

NOM :

Prénom :

Adresse :

Téléphone :

Cp :

Ville :

Adresse mail :

A remplir par le représentant légal si la personne mentionnée ci-dessus est mineure ou majeur protégé :

NOM :

Prénom :

Adresse :

Téléphone :

Cp :

Ville :

Autorise le LAMIH – UMR CNRS 8201 de l'Université Polytechnique Hauts-de-France et ses partenaires et donne la permission irrévocable de publier sur internet les réseaux sociaux toutes les vidéos et photographies prises à titre gratuit les 11, 12, 19 et 21 mai 2021 lors des tests de système interactif (lunettes de réalité augmentée).

Cette autorisation est valable pour le monde entier et sans limitation de durée à compter de la signature.

Fait à Wahagnies, le

Signature obligatoire :

IMPro de Wahagnies – 152 rue Pasteur – 59261 WAHAGNIES
03 20 86 98 80 – ud-improwah@udapei59.org

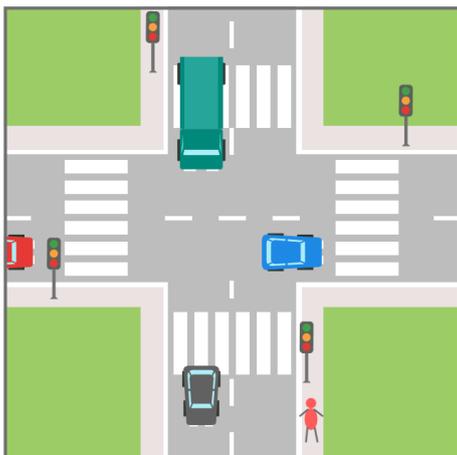
Fig. G.1 Consent for pictures usage during outdoor testing: Path Following

Appendix H

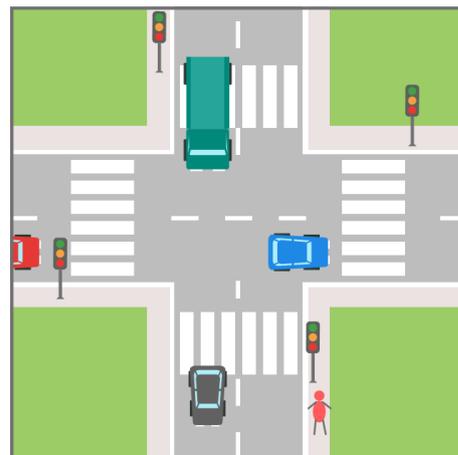
IMPRO - Mobility Worksheet

Fiche de mobilité 1 : Sens d'Orientation

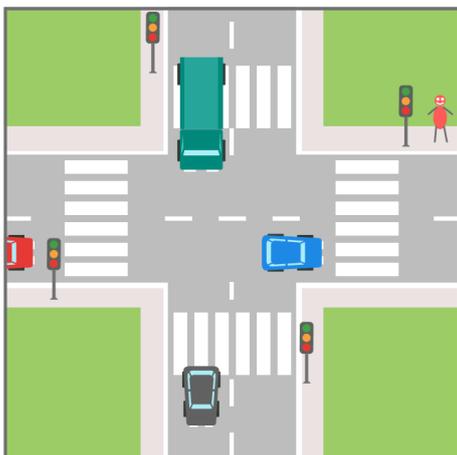
Je suis le petit bonhomme en rouge Aidez-moi à trouver mon chemin en utilisant ces flèches :



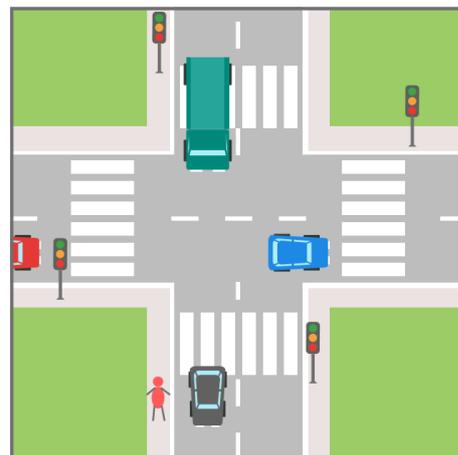
a. Tourner à droite. Indiquez le sens avec une flèche.



b. Tourner à gauche. Indiquez le sens avec une flèche.



c. Tourner à gauche. Indiquez le sens avec une flèche.



d. Continuer tout droit. Indiquez le sens avec une flèche.

Conçue lors d'un atelier de co-creation en présence d'Alexis, Pauline et Aymen

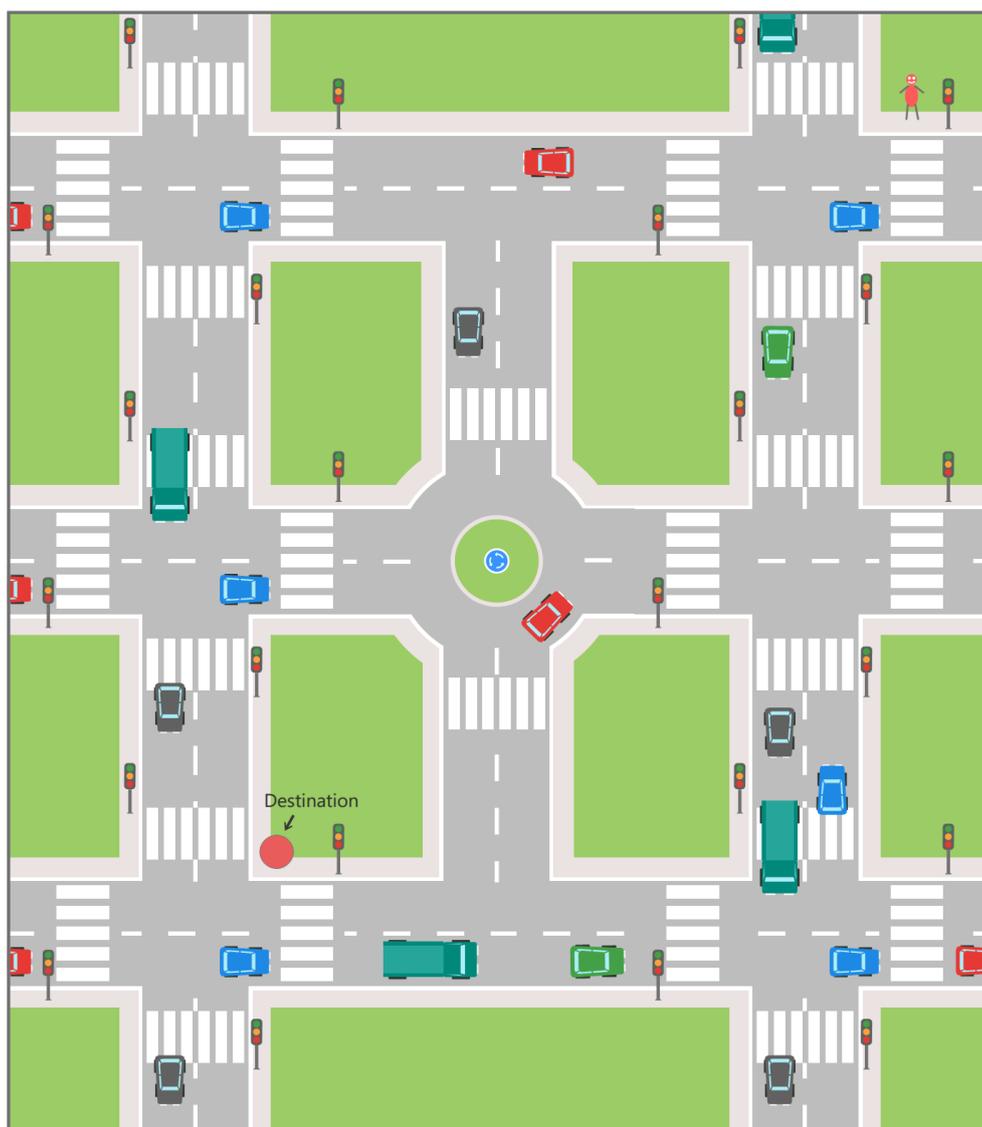
Réalisée par Aymen



Fig. H.1 Mobility Worksheet (page 1)

Fiche de mobilité 2 : Sens d'Orientation

Je suis le petit bonhomme en rouge  Aidez-moi pour arriver à ma destination  en utilisant ces flèches :



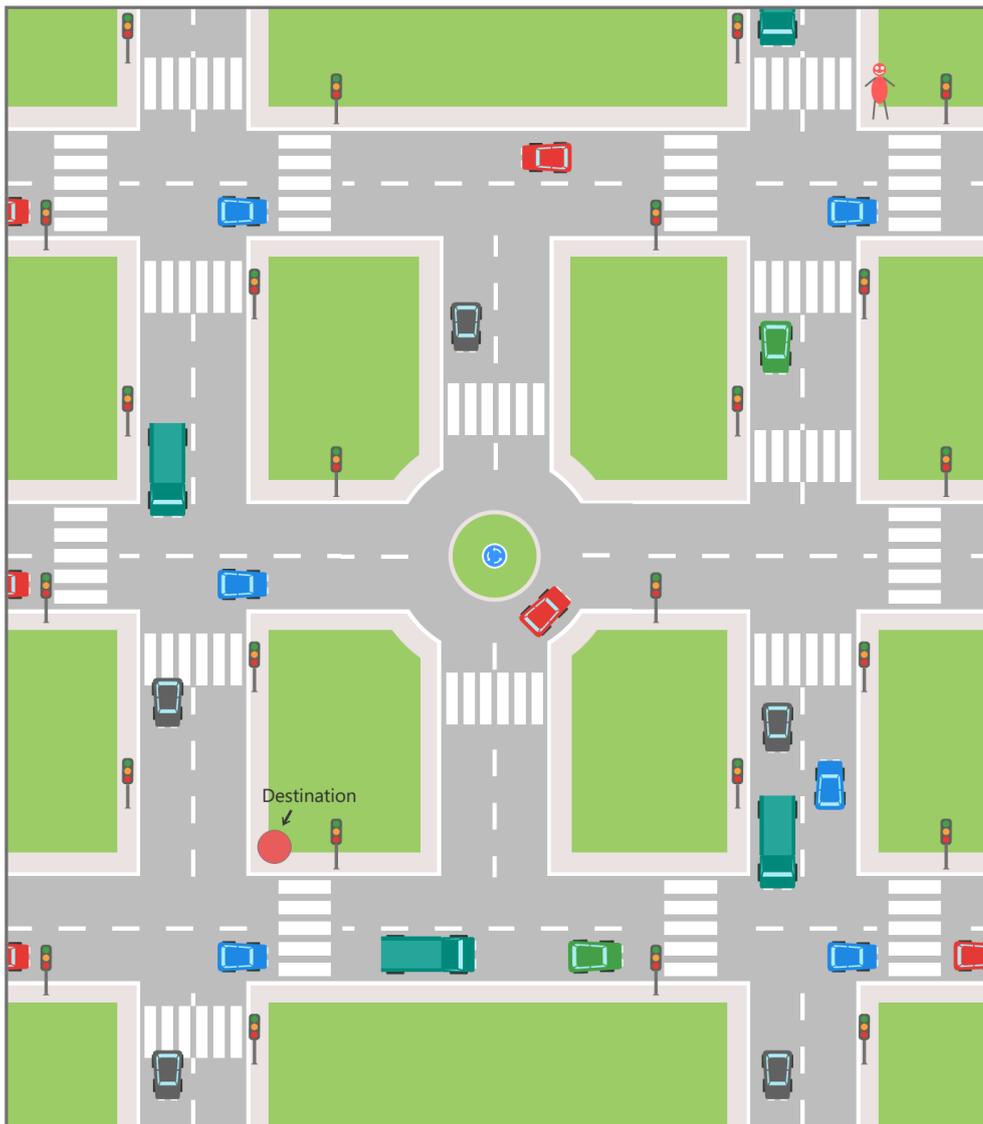
Conçue lors d'un atelier de co-creation en présence d'Alexis, Pauline et Aymen

Réalisée par Aymen

Fig. H.2 Mobility Worksheet (page 2)

Fiche de mobilité 3 : Sens d'Orientation

Je suis le petit bonhomme en rouge 
Aidez-moi pour arriver à ma destination  en restant sur les trottoirs.
UTILISEZ ces flèches ← → ↓ ↑ à chaque changement de direction :



Conçue lors d'un atelier de co-creation en présence d'Alexis, Pauline et Aymen

Réalisée par Aymen



Fig. H.3 Mobility Worksheet (page 3)

Appendix I

Publications and seminars

- International Journal
 - Lakehal A., Lepreux S., Letalle L., Kolski C. (2021). From wayfinding model to future context-based adaptation of HCI in Urban Mobility for pedestrians with active navigation needs. *International Journal of Human-Computer Interaction*, 37 (4), pp. 378-389 [DOI=10.1080/10447318.2020.1860546].

- Proceedings of International Conference with selection committee
 - Lakehal A., Lepreux S., Efstratiou C., Kolski C., Nicolau P. (2020). Investigating Smartphones and AR Glasses for Pedestrian Navigation and their Effects in Spatial Knowledge Acquisition. *MobileHCI, 22nd International Conference on Human-Computer Interaction with mobile Devices and Services*, ACM, Oldenburg, Germany, october.
 - Letalle L., Lakehal A., Mengue-Topio H., Saint-Mars J., Kolski C., Lepreux S., Anceaux F. (2020). Ontology for mobility of people with intellectual disability: building a basis of definitions for the development of navigation aid systems. *HCI in Mobility, Transport, and Automotive Systems. Automated Driving and In-Vehicle Experience Design. HCII 2020. Lecture Notes in Computer Science*, volume 12212, Springer, Copenhagen, Denmark, pp. 322-334, july.

- Proceedings of National Conference with selection committee

Publications and seminars

- Letalle L., Mengue-Topio H., Courbois Y., Lakehal A., Saint-Mars J., Lepreux S., Kolski C., Anceaux F., Pudlo P. (2020). Une ontologie au service de la mobilité de personnes présentant une déficience intellectuelle, avec une visée de conception de systèmes d'aide à la navigation. Handicap 2020, 11ème conférence de l'IFRATH sur les technologies d'assistance 'Technologies pour l'autonomie et l'inclusion' (4-6 novembre), Paris, pp. 137-142, ISBN 978-2-9571218-0-9
 - Letalle L., Mengue-Topio H., Lakehal A., Lepreux S. (2020). La mobilité des personnes présentant une déficience intellectuelle : caractéristiques, enjeux et systèmes d'aide. 13e Colloque International du Réseau Interuniversitaire de PSYchologie du DEVeloppement et de l'Education (RIPSYDEV) (8-9 Octobre), Nancy, Université de Lorraine, France, october.
 - Lakehal A., Lepreux S., Letalle L., Kolski C. (2018). Modélisation des états de la tâche de wayfinding dans un but de conception de système d'aide à la mobilité des personnes présentant une déficience intellectuelle. IHM 2018, 30eme conférence francophone sur l'Interaction Homme-Machine, ACM, Brest, France, october.
- Seminar and other papers
 - Lakehal A., Lepreux S. (2020). AR Glasses as a Navigation Assistance System to Extend Territory by Embracing New Navigation Knowledge & Skills. Workshop Entrain, Exploring New Territorial User Interfaces (visio), november.
 - Lakehal A. (2019). User-Centred Design and Evaluation of Interactive System Assisting the Mobility of People with Disability. Seminar, University of Kent, Canterbury, UK, october.
 - Lakehal A., Lepreux S., Letalle L., Kolski C. (2019). Wayfinding Modeling: a Way to Design Interactive Aid System for People Mobility with Intellectual Disability (ID). Poster, RJC IHM 2019, Rencontres des Jeunes Chercheuses et Jeunes Chercheurs en Interaction Homme-Machine (1-4 juillet), Montaignut-sur-Save, France, july.
 - Lakehal A., Letalle L., Lepreux S., Kolski C. (2019). Vers la Conception de Système d'Aide à la Tâche de Wayfinding dans la Mobilité des Personnes Présentant une Déficience Intellectuelle. Poster, Journée IHM et Santé, Metz, France, may.

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- Lakehal A., Letalle L., Lepreux S., Kolski C. (2019). State Diagram of Wayfinding Task to Design a Mobility Assistance for People with Intellectual Disabilities (ID). Poster, MdC 2019, Mardi des Chercheurs, Mons, Belgium, march.
 - Lakehal A., Lepreux S., Letalle L., Anceaux F., Mengue-Topio H., Kolski C. (2018). Le modèle de Wayfinding : une piste pour concevoir un système interactif d'aide, pour des personnes ayant des DI, dans leur mobilité. Journée IFRH du Programme Transversal Mobilité & Handicap "Les aides aux déplacements", Paris, november.

