IMPROVING THE USABILITY OF PEDESTRIAN NAVIGATION SYSTEMS

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DISSERTATION

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1. Introduction

Science may set limits to knowledge, but should not set limits to imagination.

Bertrand Russell (1872 - 1970)

1.1 Background and context of research

The explosive technological growth that has taken place in modern society over the last few decades has resulted in an increasingly rapid and mobile way of life. People move in geographical space much more than they did in the past and extensive travel to both familiar and unfamiliar destinations has become common place.

Imagine, for example, a traveller arriving by train in an unfamiliar city – being confronted with its reality for the first time as he or she exits the train station. Would it be easy for them to know where they are and which way to go without asking someone for directions, or looking at a map? And even so, is it possible to reach a planned destination without the risk of getting lost or making unnecessary detours? Often this is a difficult task. Carrying it out could be easier with the use of electronic tools such as mobile navigation systems. However, are the tools currently available suitable for the task?

The majority of activities we undertake in our everyday lives are related to mobility in some way: we live, work, shop and take our recreation in different places. Unfortunately, activity management has become very complicated, as often we only have limited time to get everything done, and this requires careful scheduling. Such scheduling involves decision-making regarding time, place and the order of activities, as well connecting and adapting them to one's overall, day-to-day activities. It is at this point that the need for information and supporting tools becomes significant. Mobile Location-Based Services can provide ubiquitous solutions for all such needs.

Location-Based Services (LBS) are information systems that use the position or location of users, provided through their mobile devices, as an integral element for providing those users with a variety of services (Gartner, 2004). From a more general perspective, however, the term LBS refers to any application that makes use of the user's location, regardless of the mobility of that user. The search engine used by Google is an example of such a system, as it can provide the search results for keywords that are related to the current location of the computer system being used – regardless of whether it is stationary (e.g. a desktop computer) or mobile (e.g. smartphones). Thus, when referring to LBS applications running on mobile or hand-held devices (e.g. PDAs, smartphones, ultra-mobile PCs), the term mobile Location-Based Services (mLBS) is preferred.

Many different types of interfaces can be used in mLBS to communicate information between an application and its user. Although the use of cartographic representations is not always an interface prerequisite (Reichenbacher 2004), this thesis focuses especially on mobile cartographic interfaces. For this reason I refer to them as elements of Location-Based Mobile Cartography (LBMC), which can be considered a sub-category of mLBS. In combination with cartographic representations, text, graphics, or even voice can be used as supplementary forms of communication in LBMC. To make a clear distinction, applications that utilize mobile cartographic interfaces will from now on be called geo-mobile applications.

Geo-mobile applications can be considered as a category of spatial decision-support tools for reliably meeting people's needs for up-to-date and location-specific information – at any time and for any place. These people could, for instance, be tourists looking for a museum, car drivers in need of navigational assistance and traffic information, or pedestrians seeking the most convenient route to take them to their destination. The potential of geo-mobile applications for addressing such problems, and any questions related to such activities, is thought to be high. However, there are still many issues to be considered that affect their practicability. The limitations of mobile devices (e.g. data communication and processing speed, small display size and slow methods of user input), the different and dynamic contexts of use and users of geo-mobile applications, and individual preferences and capabilities of users are some of the most important of these issues.

Some types of geo-mobile applications have been very successfully positioned in the market, while others have yet to gain a place. Car navigation systems are an example of the first category, while pedestrian navigation systems represent the second. There are many reasons for this, which have to do with the special nature of pedestrian orientation and navigation, as well as the way current geo-mobile applications for pedestrians have been designed and developed. For example, GPS positioning is more accurate at higher speeds of movement and on open roads than in narrow city streets, hemmed in between dense structural blocks ("urban canyons"). Also, in order to understand where they are, plan their route and reach their destination, pedestrians require map information at larger scales and higher levels of detail than that needed by car drivers. Besides, even today, during the development of many geo-mobile applications the focus is on supply-based technical approaches, rather than user needs and demands. Thus, quite often there is no deep investigation of the related (geographic) questions that potential users of these applications have or of the way they understand space and its virtual representations – for example, maps.

Often, users of geo-mobile applications do not have a clear understanding of where they are in geographic space. If they do, this is a very important first step in order to find solutions to spatial problems that they may have. These problems are often related to wayfinding, expressed through questions such as "What?", "Where?", "How far?", "How fast?", "Which way?", "Which direction?", "How long?", "How easy?", or even How safe?" In the cases of both car and pedestrian navigation systems, for example, users could become totally lost if their systems malfunctioned while they were in an unfamiliar area.

The use of maps as cartographic representations of reality is a very common and effective practice. However, users of maps differ in their abilities, capabilities and requirements. Especially when it comes to mobile maps, where the context of use plays a very large role, map use becomes much more complicated. Desktop solutions that have been traditionally used for presenting map information are not always practicable for geo-mobile applications. Desktop-made maps are too big for small screens and simply scaling down is inefficient, as it makes the maps difficult or even impossible to read (Chittaro, 2006; Kristoffersen, & Ljungberg, 1999).

The availability of pan and zoom functions is an easy and common solution for "fitting" a map to the display of a mobile device. However, this makes the handling of the map more complicated and time consuming, and users lose their overview when zooming-in to smaller sections of the map. The opposite is also true: a lot of information is usually left out of an overview (small-scale) map. This is done to prevent overloading the mobile device's display to the extent that it becomes incomprehensible, because it receives more information than it can handle. In this case, users may miss the detailed content of the map, which could make it difficult to understand the broader context of a situation. Even more advanced zooming methods – such as fish-eye views, where a map area of greater importance for the user is progressively magnified more than its surroundings – raise issues related to their usability (Yammiyavar et al., 2007; Buering et al., 2006).

According to Dey (2001), context is "any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves". In the case of mobile maps, context of use involves properties of location, orientation, time, history, purpose, socio-cultural framework, environmental setting, and system–user interaction between the mobile map and its user (Sarjakoski et al., 2004) (Figure 1.1).

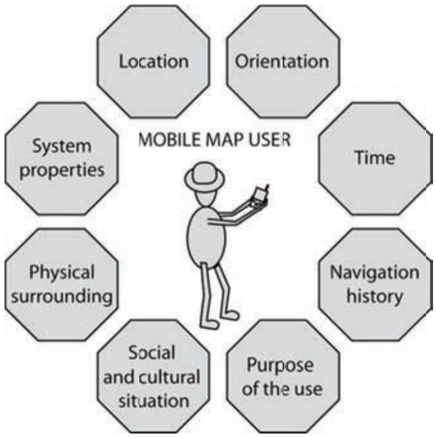


Figure 1.1: Mobile maps may be used in a variety of contexts (source: Sarjakoski et al., 2004).

The mental processes by which users in different contexts connect with mobile maps and the environment makes map representation a complex, but interesting, research problem. Personal geo-identification, for instance, the notion of "where am I", is for the mobile-map user a fundamental activity that can be influenced by various aspects of mobile-map representation. In particular, personal geo-identification is the result of mental interactions involving several sources of input: reality; the cartographic representation of reality on a mobile display; and the user's own cognitive or mental maps (Figure 1.2).

Human spatial understanding, choices and behaviour largely depend on the use of such mental maps. These are representations of reality inside the brain and are the product of knowledge derived from physically navigating in space or from information provided by maps, literature, communication with other people, or some other sources.

Although the construction and use of mental maps differs from person to person, depending on many characteristics such as age, gender, experience or personal knowledge (Lynch, 1960; Beatty, 2002), there are significant components inside them that are similar amongst particular groups of people (Gould & White, 1982; Look & Shrobe, 2007). Similarities are also to be found between the way humans use mental maps and the way they use digital maps on mobile devices. For example, human mental maps employ information generalization, where past experiences, knowledge and interactions are filtered to understand and mentally represent the current environment. Parallel to this cognitive process, generalization for mobile maps involves re-shaping and content filtering of several map scales (usually larger scales) according to predefined criteria, in order to produce a smaller-scale map that gives a more comprehensible overview.

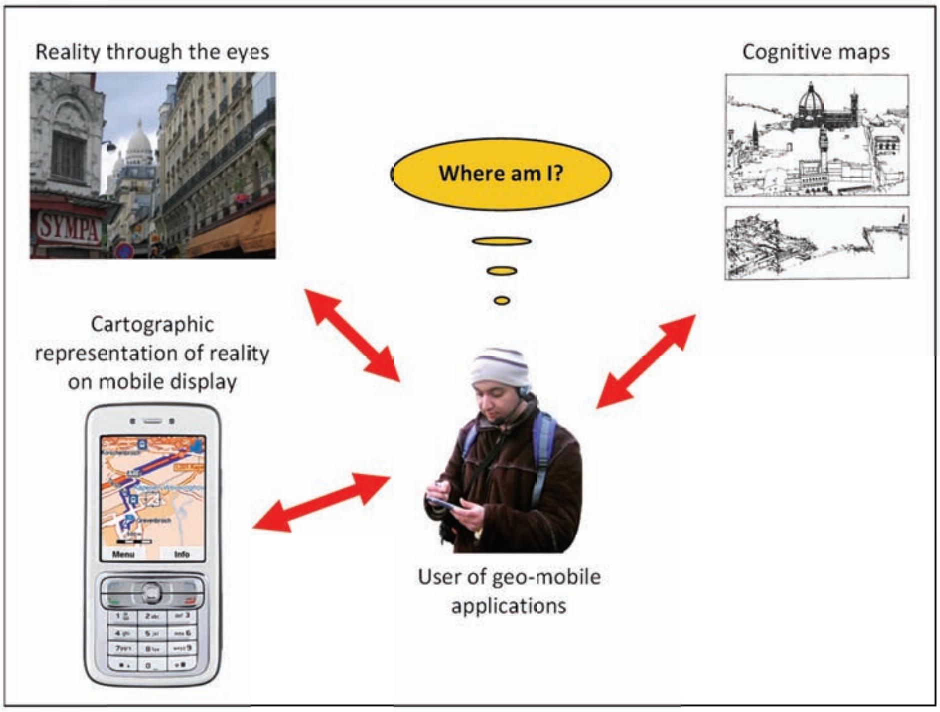


Figure 1.2: Personal geo-identification through interaction with different sources of information.

The human mind has particular ways of solving spatial problems in which different sources, scales and sensors are used – and in an order that is not always sequential. Cartographic interfaces of geo-mobile applications can only be helpful in solving such spatial problems if the information those interfaces provide is effective, efficient and satisfies users' needs; in other words, if the applications are usable. When the design and implementation of those applications is primarily supply-driven, rather than user-oriented, their usability is negatively influenced. In order to develop usable geo-mobile applications, the capabilities of the application, together with the real needs and requirements of different types of users in particular contexts of use, is of ultimate importance (Reichenbacher, 2004).

To be able to design usable applications in a methodical manner, several guidelines have been drawn up and implemented under what is known as a User-Centred Design (UCD) approach. Originating from Human–Computer Interaction science (which studies the usability of software interfaces), UCD strategies involve the investigation of users' tasks and goals, thus providing the results upon which decisions are made about the design and development of new products (Haklay & Nivala, 2010).

The process begins with identification of the need for a UCD, followed by an analysis of the requirements to be met, in which business or organizational aspects are studied together with user characteristics, tasks, preferences and contexts of use. This is the stage at which any problems with existing implementations and the satisfaction of users with solutions are investigated, and any expectations of the new design are identified. Several scenarios of use are then transformed into use cases, and rules for the implementation of early prototypes are laid down. The design of usability testing, the decisions regarding the phase of the project in which testing will be executed and the determination of the environment in which that testing will take place, as well as the methods and participants that will be involved, also belong in this stage (Nivala, 2005).

After the first task-oriented UCD prototype has been implemented, its design is evaluated together with groups of users representing ultimate target users. Possible problems with the fulfilment of user needs that are related to actual tasks to be met by the device are investigated, and this feedback is used to improve prototypes. The entire process is repeated iteratively until the result is satisfactory enough to be the final product. The UCD approach reduces the cost of implementation and can deliver greater numbers of usable products. An example of a recent research project that followed these UCD guidelines is the Dutch multi-disciplinary project on Usable (and well scaled) Mobile Maps for Consumers (UWSM2) (URL27).

1.2 Research objectives

The research presented in this thesis focuses on geo-mobile applications, their usability and the issue of personal geo-identification and navigation in space. The overall aim of the research was to design and evaluate a cartographic interface for geo-mobile applications that facilitates personal geo-identification and supports spatial activities of pedestrian users in unfamiliar spatial environments.

This main objective was made up of several smaller research goals. The first of these was to identify the links between reality, the representation of reality through mobile cartographic interfaces, and the mental maps of users of geo-mobile applications. The second goal was to model interactions between these three sources of information in order to find common elements that enable personal geo-identification and support navigation in space using mobile cartographic interfaces. Based on the model's analysis of the interactions, the content and functionality of the cartographic interface was derived and guidelines for its design were constructed. The next step, using these guidelines, involved the development (design and construction) of a showcase prototype mobile cartographic interface. In the following and final step, a reliable environment for evaluating the usability of the implemented prototype was designed, the usability was evaluated and conclusions were drawn based on the results.

In order to address these objectives, a series of research questions were formulated, focusing on a specific group of users with well-defined characteristics, needs and capabilities:

I. *Which elements of the environment, the mental maps associated with it, and the mobile cartographic interface do users of geo-mobile applications mainly use in order to orient themselves and navigate in space? Under what circumstances could they lose their mental connection with these sources?*

II. *What are the main sources of distraction in the communication of geographic information through geo-mobile applications?*

III. *What problems occur with current implementations of geo-mobile applications that have arisen from the outcomes of research or commercial projects?*

IV. *What is a convenient research approach for compiling user requirements while keeping the need for human and technical resources low, and what possible issues need to be considered?*

V. *What types of information are pedestrian users of geo-mobile applications initially seeking when trying to orient themselves in unfamiliar places?*

VI. *What types of important landmarks are there to help pedestrian users orient themselves and navigate in unfamiliar areas?*

VII. *What type of map and what type of landmark presentation would pedestrian users of geo-mobile applications find most useful when orienting and navigating?*

VIII. *What are the main problems with which pedestrian users of geo-mobile applications are confronted when trying to link reality, mobile maps and their own mental maps?*

IX. *Which are the main orientation and navigation tasks of pedestrian users of geo-mobile applications, and what related questions do they have?*

X. *What are the main information requirements of pedestrian users of geo-mobile applications that are related to the above tasks?*

XI. *What type of (new) technical solutions would improve the ability of pedestrian users of geo-mobile applications to orient themselves and navigate?*

XII. *What is a suitable environment for developing a prototype mobile interface that encompasses the above technical solutions and what problems are likely to be encountered when doing so?*

XIII. *What would be an efficient setup for testing the usability of prototype interfaces of geo-mobile applications if time and resources are limited?*

XIV. *Which prototype interface functions do users find useful, and which ones need to be improved or abandoned?*

XV. *How do users assess the usability of a prototype for meeting their objectives?*

XVI. *What are the problems and what are the benefits of the UCD-based approach followed for improving the usability of mobile cartographic interfaces?*

1.3 Dissertation outline

This dissertation has been organized in the following manner:

Chapter 2 explores different aspects of mobile navigation systems for pedestrians and considers important use and user issues in the context of personal geo-identification and navigation. In this regard, the problem of linking different information sources such as the environment, mobile maps and mental maps of the mobile users through common elements in all three sources is investigated. Various research concepts and solutions for addressing issues dealing with the limitations and special nature of mobile navigation systems (e.g. scaling, context awareness and map representation) are also reviewed.

Chapter 3 describes how current issues of geo-mobile applications for pedestrians are being addressed by some current research projects. Six different research projects are compared on the basis of their characteristics, objectives, methods and results. This chapter identifies the problems that these projects are dealing with, the degree to which research is being done on particular issues, the appropriateness of the testing methods applied, and the relation of all these aspects to my research. Chapters 2 and 3 are mainly based on an extensive review of the literature.

Chapter 4 describes the concept of UCD, i.e. the selected user-oriented research methodology for the development of a usable mobile navigation prototype that facilitates personal geo-identification and navigation for a pedestrian user in unfamiliar urban areas. In this research, a field-based experiment was used to carry out a user requirement analysis (part of a UCD approach): its results are presented and analysed here. The results helped to define guidelines for the conceptual design of a prototype interface.

Chapter 5 describes a model of user–system interactions of pedestrians using a mobile navigation interface through scenario-based task analysis of their orientation and navigation activities. User questions and information requirements are identified and use cases are determined to encompass particular technical design aspects of the prototype interface. This is followed by a description of the sequence of steps used for the software development of the prototype's interface and the tools used for implementing the software. The chapter concludes by outlining several issues and challenges that were encountered during the software development.

Chapter 6 provides an evaluation of the developed prototype, through the results of a usability testing experiment. The aims, setting, method and tasks for this test were drawn up to get clear answers to research questions related to this stage of the development process. Analysis of the results was done afterwards using a qualitative research method that provided feedback on the usability of the prototype and any improvements required.

Chapter 7 presents the overall findings of this thesis and suggests key points for further research.

A summary of the publications made in the course of the research presented in this dissertation in connection with its particular chapters, is shown in Table 1.1.

Nr.	Publication	Chapters
1	van Elzakker, C.P.J.M., Delikostidis, I. & van Oosterom, P., 2008. Field-Based Usability Evaluation Methodology for Mobile Geo-Applications. The Cartographic Journal, 45(2), pp. 139-149.	4, 6
2	Delikostidis, I. & van Elzakker, C.P.J.M., 2009b. Geo-Identification and Pedestrian Navigation with Geo-Mobile Applications: How Do Users Proceed? In Gartner, G. & Rehrl, K. (Eds.), Location Based Services and TeleCartography II, From Sensor Fusion to Context Models: Proceedings of the 5th International Conference on Location Based Services and Telecartography. Berlin Heidelberg: Springer-Verlag, pp. 185-206.	4
3	Delikostidis, I. & van Elzakker, C.P.J.M., 2009a. Designing a more usable cartographic interface for personal geo-identification and pedestrian navigation. In: Proceedings of the 6th International Conference on LBS & TeleCartography. Nottingham, UK.	5
4	Delikostidis, I. & van Elzakker, C.P.J.M., 2009c. User-centred geo-mobile application interface development for improved personal geo-identification and navigation. In: ICC 2009: Proceedings of the 24th International Cartographic Conference. Santiago, Chile.	5
5	van Elzakker, C.P.J.M. & Delikostidis, I., 2010. Use, user and usability research for mobile geo-applications for personal orientation and navigation. In: Proceedings of Professional Communication Conference (IPCC), 2010 IEEE International. Enschede, the Netherlands, pp. 121-130.	4, 5
6	Blok, C.A., van Elzakker, C.P.J.M., Razeghi, R. & Delikostidis, I., 2010. Usability of mobile eye tracking for the design of a pedestrian navigation system. Poster presented at GIScience 2010: 6th International Conference on Geographic Information Science. Zurich, Switzerland.	6
7	van Elzakker, C.P.J.M. & Delikostidis, I., 2011. User-Centered Design of Mobile Geo-Applications. In Alencar, P. & Cowan, D. (Eds.), Handbook of Research on Mobile Software Engineering: Design, Implementation and Emergent Applications. Hershey, Pennsylvania: IGI Global (in press).	4, 5
8	Delikostidis, I. & van Elzakker, C.P.J.M., 2011. Usability testing of a prototype mobile navigation interface for pedestrians. In: ICC 2011: Proceedings of the 25th International Cartographic Conference. Paris, France (accepted paper).	6, 7

Table 1.1: Publications made in the course of this research in connection with the dissertation chapters.

2. Geo-mobile applications and pedestrian users

2.1 Introduction

The previous chapter offered a general description of the aims of this research and the problems that it deals with. In particular, the research objectives, questions and hypotheses were presented. This chapter will deal with the different aspects of mobile pedestrian navigation systems emphasizing their use and users issues. In this regard, three sources of information are investigated: mobile maps, mental maps and reality, supporting the geo-identification and navigation process of the users of these systems. This process benefits from a proper linking between the three sources, and that is something that can be done through different strategies. One of them is the presentation to the mobile map users of landmarks that concurrently exist in all three sources in a way that they are both easily conceivable and confirmable. The chapter starts with an overview of the developments in geo-mobile applications in terms of representation of reality on mobile displays involving scaling, context awareness, and different map forms. Next, the concept of cognitive maps is described through early and recent research findings, mainly in the fields of psychology and geography. Following that, an outline of the reality that surrounds the mobile map users in the context of pedestrians is demonstrated, including their usual tasks, requirements and information needs related to the environment and their goals. In the end, the role of landmarks in the three sources of information available to mobile map users is explored as a means of support towards successful orientation and navigation. When, how and why landmarks are used and what are the benefits of using them as a link between real and virtual (cartographic) worlds are the issues that are explored.

2.2 Geo-mobile applications: developments and issues

In the last decade there has been a growing interest in geo-mobile applications from many perspectives: scientific, technological, and commercial to name a few. However, a common factor that affects all the above, as is the case with any software-based application and interface, is the usability of these applications. In view of the very special and dynamic use and user contexts of geo-mobile applications, location-based (geo) information has to be collected and processed, presented and interfaced with the user in efficient, effective and satisfactory ways. Presentation is in this case one of the most difficult tasks, as properly scaled, visualized, content-specific and context-aware information should be provided to the user, regardless the small size of mobile device displays.

2.2.1 Representation of reality on mobile displays

Since maps are very efficient ways of geo-communication (van Elzakker, 2003; Kraak, 2002), the same applies to mobile maps as well. With the use of maps, geographically localizing objects and retrieving information regarding sizes, distances, directions, spatial relationships and patterns are operations provided to the users (Kraak & Ormeling, 2003). Whenever a spatial search has to be executed by a moving person in an unfamiliar area, maps are the only medium that can provide information precisely and briefly (Schmitz-Belz et al., 2003).

Unfortunately, the limitations of mobile devices, especially the small size and relatively low pixel resolution of the display but also the highly dynamic context of mobile map use agitate the map use and exploration. Selecting usable forms in which the spatial information should be presented in small screens and conveniently comprehended are amongst the most important issues in this regard (Baus et al., 2002; Burigat & Chittaro, 2007; Mishra & Punia, 2005; Nivala & Sarjakoski, 2007). When mobile maps are used for navigation, for instance, displaying a global map view of the area offers an overview which lacks decent detail. On the other hand, large scale views can deliver the missing detail but this time the global context is lost (Figure 2.1). Thus scale is a critical factor for the usability of mobile maps.

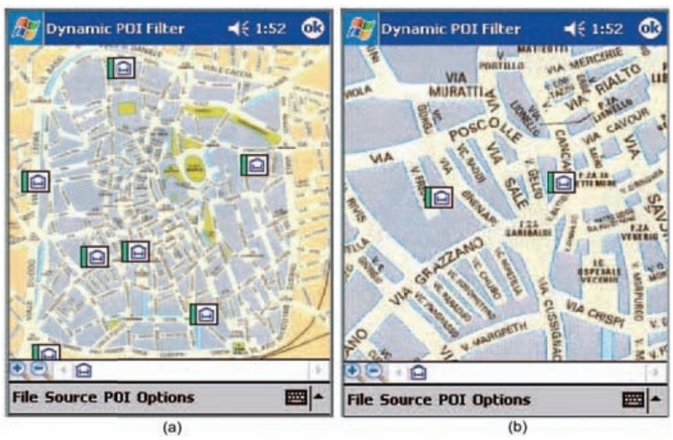


Figure 2.1: Overview map showing all the POIs of the area of interest but lacking detail (a) and detailed map view where not all the POIs can be displayed (b) (source: Chittaro, 2006).

In order to keep the balance between overview and detailed information the users of mobile maps are pushed to use zooming and panning, an operation which in the end can lead to disorientation and tiredness due to its cognitive complexity (Burigat & Chittaro, 2007; Dilo & van Oosterom, 2006). This problem will be further discussed in sections 2.2.3 and 2.2.4.

There is an extensive literature available regarding map design and graphical-based communication involving several criteria for effective map design such as completeness, visual clutter, semantic clarity, general and local placement, map and text alignment on the map and so on (Klippel et al., 2006; Reichenbacher, 2004). These can be used as a basic framework in order to design mobile maps as well. However, in order to overcome some of the limitations of the display size of mobile devices and travelling time availability of the mobile users, special adaptation of the information visualization is required.

The mobile maps should be presented in a form that is simple and clear, but still easily perceivable and interpretable by a user on the go and under time pressure (Baus et al., 2001). Further, geo-communication through mobile displays eases when visual emphasis is given only to the information required by the user (Zipf & Richter, 2002). Several efforts have been made by different researchers to increase the focus of the mobile users on the information that is useful for them. For example, visual emphasis by graphical means on map features can be provided via:

- Contrast difference: By increasing the contrast of the objects under focus and decreasing the contrast of the remaining ones or increasing the contrast of the objects compared to the background (Meng, 2004; Reichenbacher, 2004).
- Colour selection and highlighting: By highlighting objects with brilliant and sparkling (signal) colours, like yellow or pink which attract more attention than grey ones from the mobile map user (Zipf & Richter, 2002; Reichenbacher, 2004). The colours of the map features should also reflect the colours of these features in reality as close as possible (Nissen et al., 2003).
- Outline attention: By giving emphasis to the outline of an object (Reichenbacher, 2004).
- Opacity difference: By applying higher opacity to the objects under focus and lower opacity to the remaining ones (Baudisch & Rosenholtz, 2003; Reichenbacher, 2004; Umlauft et al., 2003).
- Crispness difference: By sharpening (or leaving untouched) the objects under focus and at the same time blurring the remaining ones (Reichenbacher, 2004).

- Size: By increasing the size of features such as road widths or building sizes so that more attention is drawn to them (Agrawala & Stolte, 2001; Anand et al., 2004).
- Dynamic effects: with the use of animation, such as shaking, rotation, blinking, size changing and other dynamic visual methods on map objects (Bartram et al., 1995; Buering, Gerken & Reiterer, 2006; Chittaro, 2006; Zipf & Richter, 2002).
- Map generalization: By applying a predetermined amount of generalization depending on the used scale to features belonging to a zone of interest and increasing the amount of generalization in the consequent zones. The larger the distance from the zone of interest, the greater the amount of generalization applied and the features eliminated (Agrawala & Stolte, 2001; Dilo & van Oosterom, 2006; Setlur et al., 2005; Zipf & Richter, 2002).

Besides visual emphasis, symbology is also a very important factor that influences the comprehensibility of mobile maps. Mobile map users can more easily acknowledge symbols that are based on the ones used in popular map designs or they remind signs that exist in a specific area in reality (Nissen et al., 2003). Considering the large diversity of mobile user characteristics, preferences, capabilities, information needs and tasks, mobile map symbology should be adjusted to meet the user and use context in terms of usability.

Different users can have various interests, different levels of familiarity with particular areas or heterogeneous cognitive capacities related to their age, physical abilities and educational background that influence their information needs (Zipf, 2002). For example, visually impaired persons typically demand symbols larger in size and decreased detail and children prefer simple pictorial symbols that are easy to comprehend and smaller amounts of information that can be always observed and verified in reality (Siegel & White, 1975; Zipf, 2002). Adaptation based on the user and use contexts come into play when the target is the development of usable mobile map interfaces that encompass these different needs and requirements.

2.2.2 Context awareness and map adaptation

Context is according to Merriam-Webster's Online Dictionary (URL30), "the interrelated conditions in which something exists or occurs". The origin of the term "context-aware" lies in the early work of Schilit & Theimer (1994), defined as "the location and identities of nearby people and objects, and changes to those objects."

However, a problem that this definition introduces is the inability to determine whether particular types of information that are not included in the definition can be specified as context (Dey & Abowd, 2000). According to Dey & Abowd (2000), alternative definitions for the same term given by other researchers are either simply paraphrases of impractical use, as for instance when using the terms "environment" or "situation" instead of "context" or very restricting descriptions. Taking into account the wider meaning of "context", which encapsulates the entire situation as application- and user group- related and involves different aspects depending on the situation, they gave the following definition (Dey & Abowd, 2000, pp. 3-4):

"Context is any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves." The latter definition of context is appraised by Christopoulou (2008) as the most well described and apparently the most widely used one in mobile map research. Dey & Abowd (2000) also give a definition of context-awareness: "A system is context-aware if it uses context to provide relevant information and/or services to the user, where relevancy depends on the user's task."

The development of mobile user interfaces that are context-aware, aims at enhancing the experience of the user, which discloses his or her responses triggered by the use of the system in mental, emotional and social terms. This can be done through adaptation of the system functioning determined by related modelled contextual factors (Goodman et al., 2004). Location, time, navigation history, system properties, purpose of use, orientation, physical surroundings, user personal profile and cultural and social issues are amongst the most essential of these factors (Nivala & Sarjakoski, 2003). A categorization of the contextual factors and their corresponding features in mobile map services is shown in Table 2.1.

Adaptation in mobile cartographic visualization refers to the modification of the map contents based on factors such as the context of use, the user preferences and user tasks in order to give satisfaction to the user. In order to apply methods for adaptation, first it is required to determine which of the parameters of the map are adaptable and to which extent. Conventional cartographic aspects such as title, legend, scale, symbology, extent or digital cartographic principles such as user interface, file format, zooming, panning and selection functions and hotlinking can be involved in the adaptation process (Mishra & Punia, 2005). In Figure 2.2 a categorization of adaptable map aspects belonging into three different categories is presented.

Visualization is the last category of aspects in adaptable maps in a chain between geo-information and the user. In this regard, map scaling, layout, and content presentation are predominant factors as it comes to communicating geo-information through maps to the user. Several methods and techniques that cope with these three factors which get problematic on small mobile device displays have been researched. Many times, these methods and techniques involve map and content generalization. An overview of some of the most characteristic ones is presented next.

General categories of context	Categories of context for mobile maps	Corresponding features
Computing	System	Size of a display Type of the display (black – colour screen) Input method (touch panels, buttons etc.) Network connectivity Communication costs and bandwidth Nearby resources (printers, displays)
User	Purpose of use User Social Cultural	User's profile (experience, disabilities etc.) People nearby Social situation
Physical	Location Physical surroundings Orientation	Lighting Temperature Surrounding landscape Weather conditions Noise levels
Time	Time	Time of the day Week Month Season of the year
History	Navigation history	Previous locations Former requirements and points of interest

Table 2.1: Categorizing contextual factors and their corresponding features (adopted from Nivala & Sarjakoski, 2003).

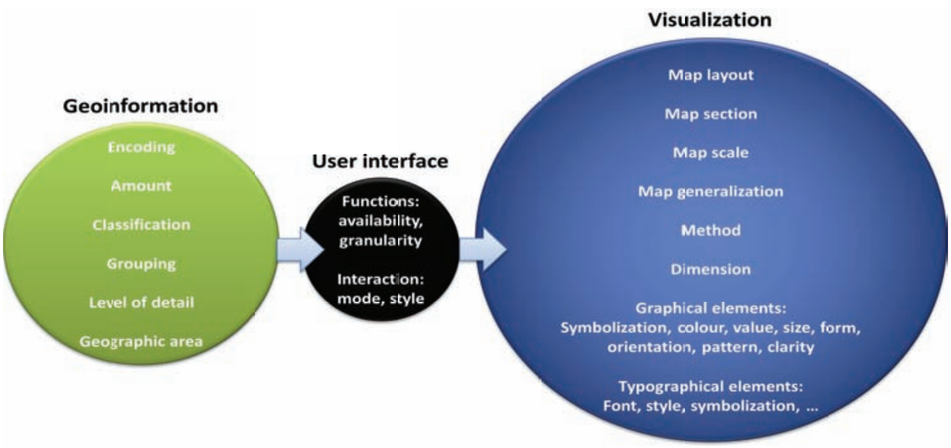


Figure 2.2: Adaptable map aspects (adopted from Reichenbacher, 2003).

2.2.3 Addressing the problems of mobile map presentation

Coming back to the problem described in section 2.2.1, in an effort to avoid graphically overloading the small mobile screens, overview maps omit a lot of information which can make screens virtually unreadable. At the same time, zoomed-in views become map fractions that seem loose from the overall understanding (Yammiyavar et al., 2007; Buering et al., 2006) or, in other words, from overview of information space (Stuart et al., 1999; Hornbaek et al., 2002). The use of zooming and panning functions is then a solution in an effort to fill the gap between overview and detailed views and build a global mental conception of the area of interest by the users.

Although zooming and panning functions are the simplest ways of viewing / interacting with a map in a small screen, they can also lead many times to a loss of contact between the mental maps of the users of the geo-mobile application, the mobile map and reality. In this case, the user cannot easily understand where he or she is in space or, in other words, successfully geo-identify him or herself. The problem is further magnified by the step-wise transitioning between different map zoom levels in the form of redrawing. This common approach in today's geo-mobile applications further triggers the repeated use of zooming and panning by the users in order to keep their mental connection with the map (Dilo & van Oosterom, 2006).

There are several efforts by different researchers to address these issues with the use of various techniques, mostly adopted from desktop environments. Examples of these techniques and the sub-section where they described are the following:

- Overview-plus-detail (2.2.3.1)
- Focus-plus-context and fish-eye view (2.2.3.2)
- Off-screen object visualization (2.2.3.3)
- Smooth (animated) zooming and panning (2.2.3.4)
- Vario-scale maps (2.2.3.5)

2.2.3.1 Overview-plus-detail

Overview-plus-detail (O+d) is a technique originating from desktop systems and it is based on the provision of two different views at the same time, an information space overview and a detailed one to the user. This approach is based most of the time on the presentation of the detailed map on the mobile display together with a small thumbnail where a large scale overview map is shown (Figure 2.3).

Figure 2.3: A traditional O+d map visualization for mobile displays (adopted from Burigat et al., 2008).

In the thumbnail, the part of the overall area that the detailed map is covering in any particular moment is highlighted, allowing, in some implementations, a direct manipulation of the detailed map view in the forms of panning or even zooming through interaction with the thumbnail (Plaisant et al., 1995).

Research has shown that although O+d approaches are generally usable in desktop applications (Beard & Walker, 1990; Hornbaek & Frokjaer, 2002; North & Schneiderman, 2000), they do not perform as good in mobile applications (Chittaro, 2006; Buering et al., 2008). The reasons for this are mainly the non-direct spatial relation between the two views and the limited size of the detailed view, requiring a great deal of cognitive effort and interaction with the interface to comprehend the map. Especially when they are used for orientation and navigation tasks, O+d solutions should perhaps be avoided (Buering et al., 2006). The overview thumbnails bind a considerable part of the space available for the detailed view and thus should be kept small, which in turn reduces their readability (Chittaro, 2006).

Partly contradictious to the above conclusions are the research findings of Burigat et al. (2008), ascertaining the ineffectiveness of wireframe O+d mobile interfaces but still indicating that traditional O+d techniques can improve navigation execution and enhance orientation of mobile map users when semantic information is emphasized in the overviews. They make this remark based on their experiments involving tasks where there is no provision of cues regarding orientation through explicitly structured information spaces. Burigat et al. (2008) believe that identification of the user's position with respect to the overall space or relative position of objects in relation to each other can be done more quickly and easily through traditional O+d mobile interfaces in this way. Thus they conclude that these interfaces can be useful for particular types of geo-mobile applications such as mobile tourist guides displaying locations of Points of Interest (POIs). At the same time, the researchers argue that more research, considering several aspects of O+d visualizations such as size, scalability and proportions of overviews is needed in order to be able to generalize their current results.

2.2.3.2 Focus-plus-context and fish-eye view

The Focus-plus-context technique (F+c) is based on the bifocal view browser approach for desktop systems where a "magnifying glass metaphor" is used. This provides a zoomed-in view of the object under magnification together with its surrounding objects (Plaisant et al., 1995). Through F+c, it is possible to provide the user with an overview (or context) and a detailed view at the same time without the need for separating them as in the case of O+d (Chittaro, 2006). Besides, this technique has low display size requirements and by using it the issue of mentally linking the colliding overview and detail views can be addressed to some extent as well (Rauschenbach et al., 2001).

Extending the concept of F+c, a technique named fish-eye view was developed, which constitutes the most common and well-known F+c paradigm. Through this approach, a large amount of magnification is applied to the centre of the user's interest decreasing progressively as the distance from that centre increases towards the periphery. Thus the central objects appear in large size while the distant ones are gradually compressed in terms of size. In this way there is no need for zooming or panning from the users' side as a deformed overview is provided all the time. However, depending on the size of the image or map, a large amount of distortion can be introduced (Plaisant et al., 1995).

Fish-eye views are difficult to implement for mobile device environments and prove to be ineffective for maps, because users want to make travel time estimations which are based on geometrical relationships (Robbins et al., 2004). Yet, local magnification of particular areas of interest and importance for the mobile map users and the compression of the remaining ones is a fish-eye variant that has shown good results with geo-mobile applications. Complicated road crossings could be examples of areas with high usefulness for the users and lengthy non-intersecting roads examples of the opposite case (Chittaro, 2006).

2.2.3.3 Off-screen object visualization

The use of zooming and panning, especially on mobile maps, can move several contents outside the display area (Figure 2.4), obstructing the users from performing important tasks involving spatial cognition. The mobile display is acting in this case as a "viewport", showing a portion of the map workspace which is much larger than what is displayed. Locating POIs and navigating towards them is an example of these tasks (Baudisch & Rosenholtz, 2003; Burigat et al., 2006). This problem is further illustrated in Figure 2.5.

Figure 2.4: The limited size display of a mobile device superimposed to a large map workspace as a viewport, where several POIs such as Metro stations (M) and Restaurants (R) are off-screen (source: Irani et al., 2006).

Figure 2.5: Users of mobile maps need to look after alternative places when planning navigation tasks (a). But when street-level information is also needed, these places move to off-screen positions (source: Baudisch & Rosenholtz, 2003).

To address these problems, off-screen object visualization methodologies are used such as Halo (Baudisch & Rosenholtz, 2003), Hop (Irani et al., 2006), CityLights (Zellweger et al., 2003), and Arrows (Burigat et al., 2006) (see Figure 2.6).

"Halo" uses circle rings that surround POIs as virtual streetlights that spread their light around (see Figure 2.6a). The arcs of these circles (or halos) then appear on particular borders of the displayed window depending on their location, allowing for an estimation of the distance of the POIs based on the size of the arcs. The larger the size of the arc, the more distant the POI is. In this way, the users can mentally recreate the off-screen space. Further, the arcs can communicate additional information regarding the off-screen POIs with the use of colour, thickness and texture Whenever there is a strong overlapping between different arcs, these are combined into double, triple arcs and so on (Baudisch & Rosenholtz, 2003).

Another off-screen visualization technique is "CityLights" (see Figure 2.6c), where points, lines and 2D objects are placed on the borders of the display in order to provide the user with clues regarding the existence, physical properties, distance, direction or interaction history of off-screen objects as well as their relationships to visible objects on the display (Zellweger et al., 2003). The "CityLights points" technique as a variation of CityLights, provides information regarding the direction of invisible objects based on the location of points on the borders of the display window and distance information (far-near) using two discrete colours. "CityLights lines" is another variant of CityLights, providing information regarding the direction of off-screen objects based on the position of lines on the window border and regarding their distance based on the line colour, thickness or labelling. The Halo technique described earlier represents an example of 2D object-based (circle-based in this instance) "CityLights", but there are still many possibilities for different interaction forms based on 2D objects (Zellweger et al., 2003).

"Arrows" is a technique similar to Halo but using arrows instead of arcs, oriented towards the off-screen POIs (see Figure 2.6b). The distance of these POIs can be indicated using size, colour, length, shape or labelling (Burigat et al., 2006).

A comparative user-based study of Halo and scaled- and streched-Arrows was carried out by Burigat et al. (2006) involving four different map use tasks regarding localization of off-screen objects and distance comparisons. Scaled-Arrows indicate the increase of distance of the objects through an increase of their size and streched-Arrows through an increase of their length. The results of the experiment suggest that Arrows provide increased efficiency compared to Halo, especially in cognitively demanding tasks and are more preferred by the users. However, Burigat et al. (2006) note that different types of visualizations may determine which technique is more beneficial for the users in terms of efficiency and effectiveness. Further, the Halo technique tended to produce more cluttering when many off-screen objects were present, thus negatively affecting the testing results. Addressing this problem could probably increase the usability of Halo.

Figure 2.6: Examples of Halo (a), Arrows (b) and CityLights (c) (adopted from: Baudisch & Rosenholtz, 2003; Burigat et al., 2006).

Contrary to the results of the previous experiment, in the initial user study of Halo executed by Baudisch & Rosenholtz (2003) a comparison of Halo with Arrows was also performed, showing an increased usability of Halo over Arrows. This was also based on four different map-based user tasks again involving locating off-screen objects and estimating proximity, but also determining a shortest-path routing through off- and on-screen objects and a routing that avoids particular on- or off-screen locations.

Considering the different results of the above studies it may be concluded that more research is needed regarding the usability of off-screen visualization techniques for mobile device environments in different use and user contexts which could involve field-based surveys as well.

The "Hop" technique, named after Halo+Proxy, is an approach based on Halo but providing at the same time fast off-screen object access. Irani et al. (2006) developed this technique in order to address the issues of cluttering due to the overlapping of multiple Halos when there are many off-screen objects. This was done by using elliptical Halos for indicating objects directed towards the four points of the compass and circle halos for the corner ones. As it comes to the fast off-screen object access, Irani et al. (2006) involved a virtual "laser beam" represented by a line uninitiated from and rotating around a centre triggered by the user by clicking, dragging and rotating the display cursor. The user interaction with the display also determines the radius of a "circle of movement" where the proxies are placed. Proxies are created whenever the beam crosscuts a Halo and they stay visible for a few seconds. If the user clicks on one of them before they fade out, the mobile display viewport (as it was shown if Figure 2.3) is transported to the off-screen object location which now becomes the main displayed area. Animation is used for this transportation (or "teleporting") as a loss of orientation by the users was observed in case of immediate transfer to the object's location (Irani et al., 2006). The sequential stages of the Hop technique are illustrated in Figure 2.7.

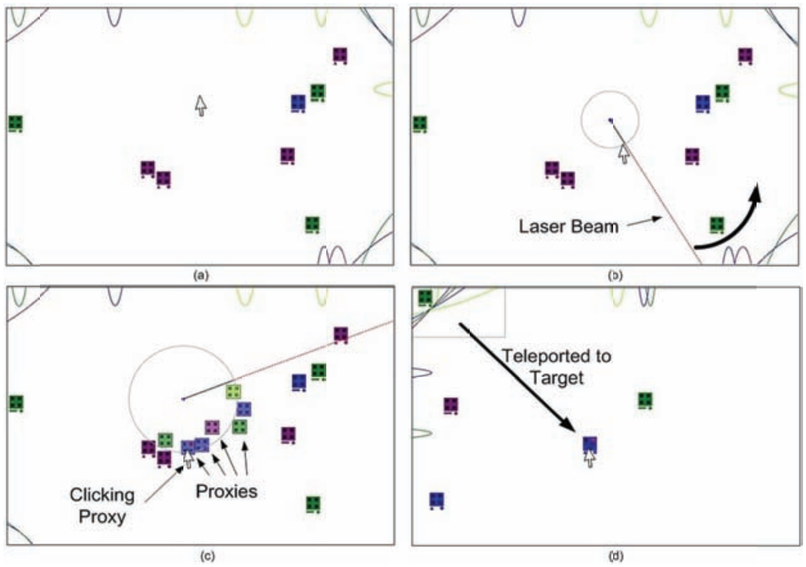


Figure 2.7: Hop sequential stages: (a) initial view, (b) laser beam created and rotates counter clockwise , (c) proxies created and collected on the circle of movement whenever the laser beam crosscuts a Halo and (d) a clicked Proxy results in teleportation of the user to the target object (source: Irani et al., 2006).

According to Irani et al. (2006), although there are still several issues to be considered related to Halo-based approaches as well as F+c techniques in general, Hop can be used in mobile devices after properly adjusting some parameters as for example decreasing the Proxy visibility duration and scaling the Proxies. Their user survey results showed a good potential for Hop over pan and zoom techniques and thus further development of the Hop was planned.

2.2.3.4 Smooth (animated) zooming and panning

The research on smooth zooming and panning methods for information spaces originates in the early nineties when prototype interfaces like the Perspective Wall (Mackinlay et al., 1991) and PAD++ (Bederson & Hollan, 1994) were developed. The Perspective Wall aimed at integrating overview and detailed views of document workspaces in a smooth way through the use of, among other things, smooth scrolling and zooming which were considered as more human-eye compatible. PAD++ explored the use of smooth zooming as a solution to the problem of preserving an interrelation between the subject of focus and its position with respect to the remaining data when navigating large data spaces. The use of uneven animation or step-wise zooming can induce disorientation and does not effectively assist cognition and perception operations necessary for the visualization and navigation of information interactively (Bederson & Hollan, 1994). In addition, the use of semantic zoom was investigated by these researchers, through which a document gradually reveals its contents as the user performs zooming-in to it.

Bartram et al. (1995) proposed solutions for exploring large information spaces in small displays by identifying six attributes that an interface technique should encompass for presenting detailed views of a global context involving time-crucial systems. According to these attributes, for example, manifold detailed views should be easily visible and a smooth transition between the different views should be executed.

These guidelines can be beneficial to different cases of navigation of information spaces through graphical displays including map interfaces. Even so, the application of some of these guidelines to mobile displays is challenging due to the small screen size. For instance, maintaining the relative location of nodes without introducing large amounts of distortion to other contents of the map may be not always easy. Using off-screen object visualization, described earlier, could be one of the sound solutions to this issue.

Smooth zooming and panning are more often termed as animated zooming and animated panning or scrolling. Robertson et al. (1991) argue that interactive animations utilize the human's system of perception in a way that the cognitive load is reduced. Besides, the user tasks become more pleasant as the interface and its contents become more alive. In addition, the animations support the user's effort to conceive the construction of information more extensively.

In general, there is still no clear conclusion regarding the efficiency of animations as this is a matter of controversy among scientists with different backgrounds. However, there is certainly a shift towards animation use at least in web applications, incited by the interest of people in this type of techniques

(Midtbø & Nordvik, 2007). Although research on the usability of animated transitions has mostly focused on non-cartographic visualizations, there are indeed several examples of relevant map-related studies. One of the pioneer researchers in this field, Monmonier (1990), introduced the idea of using a script-based process for controlling map series visualization. Koussoulakou & Kraak (1992) concluded that the understanding of maps is not significantly changed when animations are used instead of static maps. DiBiase et al. (1992) and MacEachren (1994) successively brought in six dynamic variables of animation, further supporting their ideas regarding the importance of map animations in cartography and scientific visualization when geographic change is explored. These variables are: duration, order, rate of change, frequency, display time and synchronization.

One of the more recent ones is the work of Midtbø & Nordvik (2007), who compared the use of step-wise and animated zooming and scrolling for web maps through an on-line experiment in which 200 test persons participated. In order to get an insight in the users' perception of web maps when animated scale and position transitions are used, the test persons were asked to localize a point on the map after step-wise and sliding zoom and pan was automatically performed by the system. Two versions of the experiment were executed, providing long- and short-duration zooming and panning operations respectively. The results showed that for the same duration of zooming operations, sliding zooming creates better understanding of the map locations. However, the automated zooming execution could have negatively affected the test persons' performance during the step-wise zooming tasks but on the other hand this indicates the preference for sliding zoom in situations when automatic or fast zooming is required. Midtbø & Nordvik (2007) also notified the significance of landmarks when using both of the zooming techniques, and especially the sliding zooming, helping people to identify locations by relating them to landmark objects. In case of step-wise zooming, though, the test persons relied more upon local map detail to identify locations, meaning that different map levels should maintain visual variables such as colours constant in order to promote the users' orientation (Midtbø & Nordvik, 2007).

Considering the usability of animated zooming for maps on mobile displays, there is still only little research executed, mostly due to the limitations of mobiles devices in computing power required for the animations. Instead, techniques involving animated zooming and panning could be used in the future in mobile devices, such as speed-dependent automatic zooming (SDAZ) (Igarashi & Hinckley, 2000; Buering et al., 2008). These are currently implemented and tested on desktop computers and tablet PCs. In many cases a preference towards the use of smooth mobile map transitions is indicated

(Nivala et al., 2003; Reichenbacher, 2004; Dilo & van Oosterom, 2006; van Elzakker et al., 2008). In this regard, the need for further experimental evaluations of existing geo-mobile applications using smooth zooming is indicated (Looije et al., 2007; Delikostidis & van Elzakker, 2009b).

2.2.3.5 Vario-scale maps

The use of non-uniform scaling constitutes another alternative solution to the problem of providing the mobile user with both overview and detailed maps. It shares some visual similarities with the fish-eye view described in section 2.2.3.2 but uses a different context. Variable scaling in terms of generalization is applied instead of variable magnification-compression of objects depending on their distance from the user's centre of focus. Thus, the area of the map that reflects the surroundings of the user's actual position in reality is presented at a large scale and the further areas at a smaller scale. In fact, the circular area of user focus uses a map scale that is equal to the actual scale of the selected dataset for the particular use context and the remaining map areas use scaling derived from real-time generalization operations (Harrie et al., 2002).

Using the SVG language and particular mathematical algorithms, Harrie et al. (2002) were able to produce this type of visualizations to be used in the GiMoDig project (Nissen et al., 2003). The examples of a map grid distorted after applying the vario-scale mapping technique and an actual vario-scale map visualization are shown in Figure 2.8.

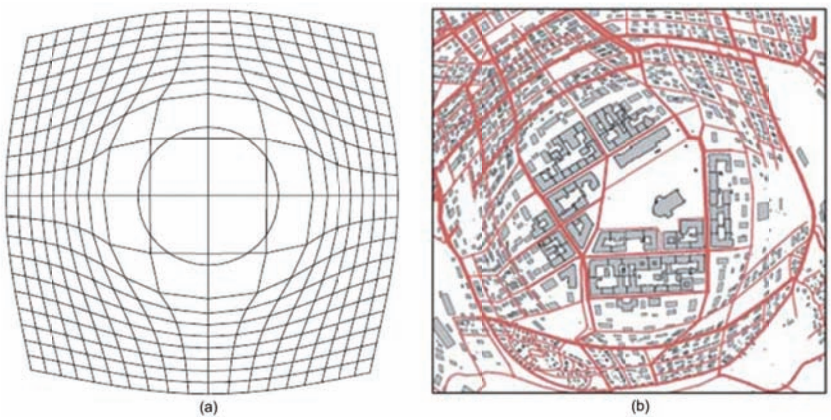


Figure 2.8: Vario-scale map distorted grid (a) and the actual visual result (b) (source: Harrie et al., 2002).

One of the problems that vario-scale maps demonstrate is the non-smooth scale change between the circle of focus and the parts outside of it. For example, a big object that lies both inside and outside the focus circle will have a discrete change of size along its length, something that could confuse the map users (Harrie et al., 2002). Reichenbacher (2004) also highlights another problem with this type of implementations, which is the cluttering of the map at the borders of the display. Thus he proposes the use of radial generalization, where simplification is applied in a radial manner from the focus centre to the outlines of the map, as a more convenient solution.

The use of vario-scale maps together with smooth zooming in order to improve the usability of mobile maps was an approach investigated by Dilo & van Oosterom (2006). This is still a field of research that shows a great potential for further studies and development.

2.2.4 Map orientation and navigation differences between individuals

Humans construct mental spatial representations of reality based on coordinate systems or Frames Of Reference (FOR) where the observed real objects are mentally positioned depending on the spatial relationships to each other and the observer. The root, orientation and axe interrelations determine the type of any FOR, which can be egocentric or exocentric. The former originates from the observer's viewpoint and its axes are in alignment with his or her body. Thus egocentric FORs represent personal aspects of reality. An example of a "you-are-here" egocentric map, where the map is in alignment with reality and the reference of the map (absolute) is in line with the reference of the user (egocentric-relative), is shown in Figure 2.9.

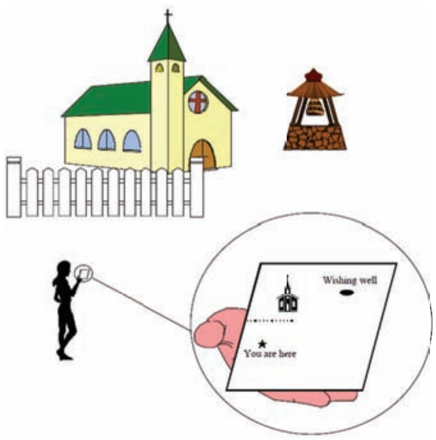


Figure 2.9: A "you-are-here" egocentric map properly aligned to reality (source: Hunt & Waller, 1999).

Through experience humans become able to identify objects from various positions irrespective of their own position and they construct FORs originating from the objects, or exocentric FORs (Bidwell et al., 2005).

While traditional maps are most of the time exocentric, the use of egocentric approaches continuously increases due to the technological advances in cartography and the development of new personalized geo-applications. Mobile vehicle navigation systems are examples of applications where egocentric map views such as heading-up, bird's eye views and 3D perspective views are widely used (Meng, 2005).

The effect of map orientation on the performance of map users during spatial task execution, such as orientation and wayfinding, and their cognition of space have been reported in many studies. Although a large amount of those studies refer to paper and desktop maps, their results apply to mobile maps as well, as the fundamentals behind map use are to a large extent similar. In general, two main types of map orientation are used. The North-up, when the top of the map is aligned to the North as what happens with traditional paper maps, and the heading-up or track-up when the top of the map is aligned towards the direction of the user's movement or field of vision. Each of the approaches shows particular advantages or disadvantages depending on the context of use and the user characteristics and preferences.

For example, North-up maps generally promote situational awareness of the users, as they represent reality continuously in the same manner. On the other hand, heading-up maps reduce the cognitive load needed for a mental map rotation in order to align the map with the user's position in reality, supporting wayfinding tasks (Winter & Tomko, 2004; Smets et al., 2008). For example, Willis et al. (2009) executed an experiment where the tests persons' navigation performance using a North-up against a heading-up map in a victim rescue situation was investigated. The results showed that the test persons who used heading-up maps performed reasonably better.

However, there are large individual differences in map orientation preference, related to the individual's orientation abilities and characteristics. In an earlier study, Bovet (1992) investigated whether students who were transported some kilometers away from their campus could point back to it. The results showed a large deviation between the students' direction estimations and the correct direction of the campus in reality (Figure 2.10).

Age also plays a role in spatial orientation. Cornell & Alberts (1994) stated that very often children below ten years old lose their way, while their spatial learning abilities in unfamiliar environments reach the levels of adults by the age of twelve. The opposite happens when adults get older. Then their orienting and wayfinding performance gradually decreases (Salthouse, 1991). However, there is lack of field-based tests to verify these research findings further (Hunt & Waller, 1999).

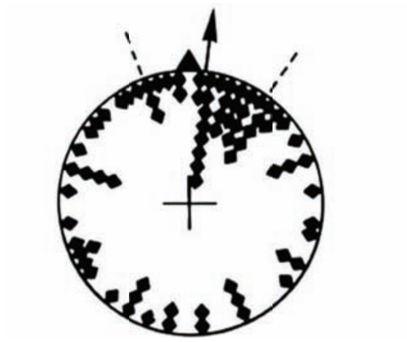


Figure 2.10: Graphical representation of the resulting individual direction data points in the research of Bovet (source: Bovet, 1992).

Cultural background is another factor that influences orientation and navigation strategies and performance. In this regard, cross-cultural diversity on the landmark nature and use as well as route and scene perception and description have been reported already (Spencer & Darvizeh, 1983). A study done by Montello & Freundschuh (2005) concluded that different cultures preserve different internal representations of the environment which can be brought up in particular environmental settings and support spatial activities. Cultural origin, according to Ramadier & Moser (1998) predetermines also the different characteristics of environmental metaphors (social, physical, functional, use, or landmark-related). They quote, for instance, that people from African countries mostly pay attention to the functionality metaphor and people from European countries to both functionality and physical characteristics. In general, it is shown that populations belonging to primitive civilizations show a superior performance when it comes to map use and navigation (Bechtel & Churchman, 2002).

2.2.5 2D, 3D and bird's-eye view map perspectives

To be able to orient and navigate with the use of mobile maps, the user of the map should acknowledge the relations between the references of reality and the mobile map. When, for example, the user is given a particular POI on a map and he or she has to recognize it in reality, two fundamental tasks have to be executed. The first one is to determine the locations of spatial entities in correspondence to his or her location in reality and the second one to navigate to chosen destinations. Navigation itself largely relies on route division based on successive landmarks along a route, again involving the comparison between and the use of different spatial references (Oulasvirta et al., 2009). The use of one of the two current standard mobile map presentation methods, 2-dimensional (2D) or 3-dimensional (3D), considerably influences the navigation performance and spatial reference understanding strategies of mobile map users. 2D mobile maps share the same principles with that of paper maps with which most of the people are familiar, while 3D maps offer additional advantages on understanding reality and its entities (Berg Insight AB, 2007).

Through 3D maps it is possible to visualize the volume of spatial entities and provide directional multi-views on geo-data and pictorial, detailed representations. These allow for straightforward object recognition, and allow for bigger movement freedom in contrast to 2D maps. In general, 3D maps should follow an egocentric reference frame where the view of reality should be in alignment with the mobile map viewpoint (Oulasvirta et al., 2009). Examples of 2D and 3D mobile maps, showing the same area in the city of Amsterdam, are shown in Figure 2.11.

Figure 2.11: Examples of 2D (on the left) and 3D (on the right) mobile maps of the same area of Amsterdam. The first is taken from Google Maps and the second one from the iGo My way v.8.0 geo-mobile applications.

Although 3D mobile maps show a good potential, experimental user research findings suggest that 2D maps, especially when well designed, are still preferable to 3D maps (Oulasvirta et al., 2009). With the use of 2D maps, the mobile map users are guided to find and make use of well-known and all-round available cues such as road patterns and street name signs. In that case they take advantage of their cognitive maps and body movement, lowering their cognitive efforts required to orient themselves and navigate. The same does not apply to 3D maps, as there is no consistency on the street-level perspective and the use of 3D photorealism is problematic on small displays. Viewpoint rotation confuses egocentric reference alignment further. Still, when orientation and navigation strategies similar to the ones used for 2D maps are applied with 3D maps, the user's performance can be improved (Oulasvirta et al., 2009).

Using 3D maps on mobile devices can also be problematic due the limited processing power of these devices as well. Delikostidis & van Elzakker (2009b) noticed that the use of 3D maps in geo-mobile applications can significantly slow down the performance of the mobile device, making it virtually unusable in cases where many 3D buildings are shown on the map. This is a usual phenomenon in big city centres and affects the proper functioning of fundamental user operations on the map, such as zooming and panning. Besides, it interferes with other CPU power-intense functions such as smooth zooming. These malfunctions result in frustration and spatial confusion of the mobile users, who would prefer to have a very limited number of important landmarks or even just photos of them rather than a full 3D map.

An additional map presentation form that is commonly used nowadays for mobile maps is the bird's-eye view, where the area of interest is shown as if the user was flying over it at a low altitude. Many times a bird's-eye view is used to give the illusion of a 3D map to a 2D map, applying a geometric transformation that makes the 2D map shown in a tilted angle. A bird's-eye view is also common in 3D maps, especially in geo-mobile applications made for both pedestrian and car navigation. iGo My way v.8.0 in Figure 2.11 is an example of the above. The use of bird's-eye views does not provide significant advantages over 2D maps in the context of pedestrian mobile users who many times prefer street-view perspectives rather than distant ones (Delikostidis & van Elzakker, 2009).

2.3 Spatial perception and cognition

In general, perception defines the process of acquisition, translation, selection and classification of information input from different sensors of an organism in order to figure out what exists out in the world and triggers an "immediate discriminatory response" to this information. The sensors are, among others, visual, auditory, haptic, taste and smell (Bartley, 1969; Adelson et al., 2004).

According to Garcia-Mira & Real (2005), research regarding perception of the environment investigates the formation and handling of mental representations of the surroundings of humans in order to more effectively interpret and comprehend them. Although spatial perception as a natural process is as ancient as human beings are on Earth, Tolman (1948) was the first one to use the term "cognitive map" in order to describe these mental representations. The (psychological) research on spatial cognition itself actually appears in the early 20th century. Representative early examples are the related works of Trowbridge (1913) and Gulliver (1908).

Trowbridge (1913), having studied the work of Gulliver, who researched the influence of map orientation to children's geographic learning, noticed differences in the orientation capabilities between different persons and tried to find explanations for the frequently observed human spatial confusion. He argues that there are people who are using virtual maps in their minds where their homes are the central points and those who are using a more "egocentric" approach, combining their own position with the visible surroundings in order to understand where they really are and navigate. The first group of people could easily be disoriented when they have to travel to unfamiliar areas, while the latter can still keep their sense of location (Gould & White, 1982).

The development of humans' spatial cognition is based on two methods. The first is the procedural, where spatial knowledge is acquired through physical navigation within the real world, exploring it and mentally reconstructing it from the collected inspections and observations. This collection consists of assumptions regarding, for instance, what exists in the place where I am now, what exists next to this place, what direction I should take in order to go to the shopping centre and the like. It involves interaction with the environment in a sensory-motor system, based on the actions "look-find target-move towards target-look". The second is the survey-based method, where spatial understanding originates from (graphical) map reading through an overview/survey approach. It recreates space and the spatial problem in the memory, and then reasons it in terms of representation (Vestavik, 2004).

There are several controversies regarding which of the above mentioned methods is the most efficient, but according to Golledge et al. (1995), both can benefit from each other. Map use improves the understanding of the environment through natural travel-through and geographic education enhances the spatial information acquisition ability, supporting the understanding and interpretation of the real world and the execution of navigation tasks.

Large scale environment cognition has been a topic for research inside several fields of behavioural and spatial sciences, including psychology, urban planning, geography and computer science. Especially the latter has highly contributed to the evolution of spatial cognition research by providing a variety of special computational tools such as GIS and Artificial Intelligence (AI) during the exponential technological growth of the last decades. Despite that fact, the related scientific output is still moderate (Hannes et al., 2006).

There are several alternative names for the cognitive maps used by different researchers, such as "abstract maps", "cognitive space", "mental images" and "mental maps" (Kitchin & Blades, 2002).

2.3.1 Visualizing mental maps

Mental maps generally represent the spatial knowledge and understanding inside the memory of humans. They are at the same time a mental process and a product, very important for spatial behaviour and decision support.

"Cognitive mapping is a construct which encompasses those cognitive processes which enable people to acquire, code, store, recall, and manipulate information about the nature of their spatial environment. This information… is an essential component in the adaptive process of spatial decision making." (Downs & Stea, 1973). Searching inside a refrigerator, performing a transcontinental trip or crossing a big city area, are all just a few paradigms of activities involving the use of mental maps (Mondschein et al., 2006).

There is a lot of discussion regarding the processes of development and utilization of mental maps by humans, and also about the components that constitute mental maps. One of the main ideas is that personal mental maps are actually dynamic and include many different types of information rather than being just a replication of the graphical, static maps (Hannes et al., 2006).

What actually happens inside the human mind is a reshaping of the natural environment. Thus there, for instance, distances do not follow the well-established rules of cartography, as scale appears to be non-uniform. The often visited places, for example, are subjectively perceived as being closer compared to foreign or just unfamiliar ones, regardless of their real proximity (Letenyei, 2007).

The effort to visually recreate the mental maps of people in order to investigate their peculiarities has led to interesting research results. A usual method has been to ask participants to draw a map of an area, either large or small scale, depending on the motivation of each research. Lynch (1960) argues that mental maps are comprised of landmarks, edges, districts, paths and nodes, which with their appearance can influence the "legibility" of a particular place, i.e. the easiness of apprehending the layout of it by the people.

He carried out his research in three cities; Boston, Jersey and Los Angeles. By collecting and combining sketch maps drawn by the participants, together with their descriptions of each city and imaginary trips inside them, he found that there are similarity patterns between different people's mental maps (Figure 2.12).

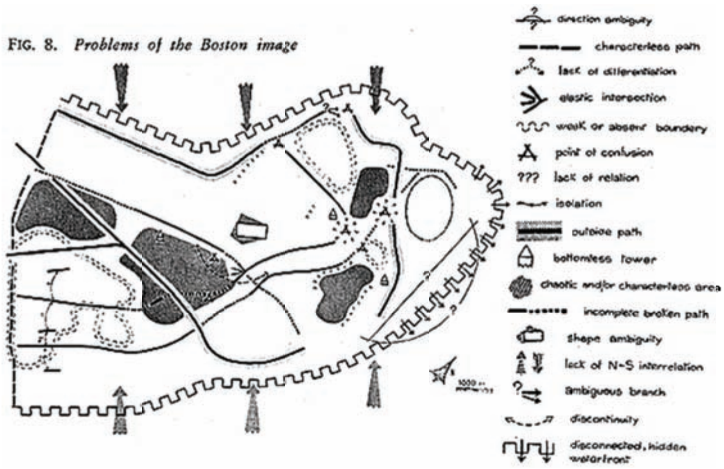


Figure 2.12: Sketch of (mental) map of an area of Boston (source: Lynch, 1960).

Some of these individuals' mental map consistencies are the execution of off-routing in order to pass through a meaningful/important city part and the attraction to natural beauty landmarks involving water and vegetation. Besides, increased confusion was shown about in parts of the cities which have no distinctive characteristics. Based on his findings, Lynch also proposed the term of imageability, which ranks the amount of remembrance and interest of an area or object to the people (Sundilson, 2009).

Recreating the mental maps of people through research methods is an interesting technique which can reveal the spatial elements that are important for their orientation and wayfinding processes. Combined with properly selected testing methodologies applied to user surveys involving the execution of spatial tasks, it could be a very helpful tool for the design of more usable geo-mobile applications supporting personal geo-identification and navigation. This approach can be essentially followed as part of the requirement analysis stage of the UCD–based mobile interface development for these applications in this research.

2.4 Reality and the context of pedestrian mobile map users

Although, mobile vehicle navigation systems have been commercially very successful types of applications, mobile navigation applications for pedestrians are still an emerging and less developed field of research. Considering the differences in the context of use (see Section 2.2.2) between car drivers and pedestrians and their different needs, their information requirements differ as well. But pedestrian navigation applications are also divided into different categories, based on the type of use and user they refer to. According to Millonig & Schechtner (2007) the types of use are:

- Tourism
- Business trips
- Recreational trips
- Rescue services
- Individual navigation aids
- Military and security operations.

It is very important to understand the navigation tasks of specific user groups in particular contexts as well as the required information in order to design and implement usable pedestrian navigation systems (May et al., 2003). The problem is that such systems are still largely based on car navigation systems in terms of conceptual, data and implementation levels (Krueger et al., 2004). The same applies to the datasets used, which conveniently fit the latter purpose but not pedestrian aims (May et al., 2003).

2.5 Connecting reality, mobile maps and cognitive maps

2.5.1 Mental maps and mapping applications

There are several recent efforts to increase the involvement of the mental mapping of people to the development of mapping applications. For example, Look & Shrobe (2007) investigated the mental models that citizens of Boston city have about it. Based on that context, they attempted to create directions for the development of mapping applications that are easier to be perceived and used by humans. The role of several prominent places and points inside the mental maps proved significant as it helps humans to specify and conceptualize unfamiliar or new places.

These places were categorized as specific, belonging to large land areas, highly populated because of cultural or commercial activities, and geography-based neighbourhoods. The final model that has been developed based on a 30-user testing survey, includes a frame of the most used city roads together with important places which are mostly transport landmarks such as subway stations or the areas around these landmarks, indicating their importance (Look & Shrobe, 2007).

The final conclusion was that the understanding of mental mapping, and the core objects around which they are formed, enables the development of map-based applications that, besides helping navigation through the presentation of landmarks, also support the upgrade and expansion of current mental maps with new useful information.

2.5.2 Mental maps and the role of landmarks

The importance of landmarks as features of the environment that support orientation, wayfinding and navigation in urban areas has been confirmed in many early studies belonging to the fields of cognitive science and urban planning (such as Tolman (1948), Lynch (1960) and Appleyard (1976)). Landmarks help structuring spatial knowledge about an unfamiliar environment and act as confirmation points of route directions and decision points. Siegel & White (1975) define the knowledge about them as "the knowledge about discrete objects or scenes that are salient and recognizable in the environment". Initially, when someone is moving through a new environment, there is an empty space cognitively between landmarks which is then scaled up through experience (Ishikawa & Montello, 2006). Over time, the person is acquiring route knowledge which is based on the patterns and sequences of landmarks related to particular decisions, such as changing of direction and distance to be travelled. The ultimate stage of spatial knowledge is survey knowledge, when the layout of the environment can be represented mentally in a pattern similar to a map with two dimensions and a scale (Siegel & White, 1975). Distance and direction relations between landmarks that have or have not been directly surveyed can be obtained from this cognitive or "mental map". Golledge & Stimson (1996) argue that during the spatial knowledge acquisition, which includes the previously described stages of landmark, route and survey knowledge obtainment, the most important action is selecting objects and/or places that have easily observable characteristics. Some of these characteristics are size, visual form, clarity, dominance, colour, contour, architectural design, location, proximity to other cues, functional class and shape.

Along with that, Golledge & Stimson (1996) point out the involvement of several factors including directional distortions, objective and subjective distances and gaps of knowledge in the procedural level of spatial knowledge acquisition. As a matter of fact, route knowledge is a collection of procedural summaries regarding successive start (or anchor) points, midway decision point identification, direction choices, path section recognition and succession, travelling mode choices, destination selection and endpoint identification.

In this manner, determining locations along a path or landmarks existing on or close to path sections where decisions regarding navigation activities have to be made is an integral procedure of survey knowledge obtainment. Much as the acquired knowledge about a route is better, more midway landmarks or intersection points can be recognized and classified into different order nodes and segments (Figure 2.13).

The primitive processes of perception and cognition of the spatial environment, involving among other things the acquisition of knowledge regarding landmarks, patterns of paths, distances and directions was named "cognitive mapping" by Downs & Stea (1973). This knowledge is used, for example, by people to travel to destinations, understand instructions for navigation or give them to others, translate maps and organize traveling plans in an adaptive way, meaning that direct experience of the environment is not always necessary in order to accommodate spatial activities (Ishikawa & Montello, 2006).

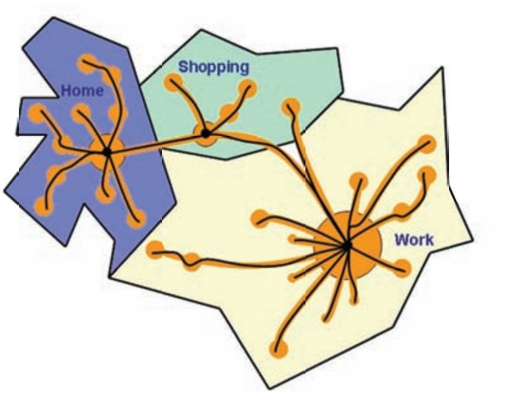


Figure 2.13: Schematic example of the Anchor point theory (adopted from Golledge & Stimson, 1996).

2.6 Conclusion

This chapter outlined the theoretical background of this research, introducing current issues and solutions regarding the representation of cartographic information on mobile displays, demonstrating the role of cognitive maps on the development of spatial knowledge and execution of spatial tasks and it described the context of pedestrian users of geo-mobile applications in unfamiliar places.

Personal geo-identification and navigation in unfamiliar places using geo-mobile applications requires information from reality, the mental maps of the users and mobile cartographic interfaces. Applying usable technical solutions to the latter can improve the user interaction between all sources of information. However, the limitations of mobile devices make it difficult to provide the users with all the spatial cues they need in order to carry out their tasks effectively, efficiently and with enough satisfaction.

Landmarks, as important spatial reference points, could help coping with these issues if proper methodologies for selection, presentation and interaction with the users are developed, based on the users' preferences, contexts and profiles. In this regard, it would be very helpful to directly or indirectly reveal the structural elements of their mental maps using properly designed experiments. Then it would be possible to select the ones that act as links between the mobile user's real and virtual worlds.

Some of the techniques coping with the presentation problem that were demonstrated in this chapter, including Overview+detail maps and animated transitioning also show a good potential for improving the usability of mobile maps. The former helps to conceptualize and explore a geographical space in an abstract and at the same time detailed perspective without the need for continuous zooming-in and -out and the latter has become a promising technique for sustaining the user's mental connection with the mobile map while zooming-in and out. In fact, these techniques lack enough implementation and testing in real contexts of use and they are a good field for further research and development here.

At this point it is useful to investigate which methods and techniques for mobile map representation have been implemented in research prototypes or commercial applications for mobile pedestrian navigation and to which extent. By critically assessing the current state of the art in the field in relation to the conclusions of this chapter, the focus of this research can be further determined. This is the aim of the next chapter.

3. Issues addressed by geo-mobile applications

3.1 Introduction

In the previous chapter several methods and techniques for visualizing cartographic information on mobile displays and the related issues were presented among other things. In many cases, these methods were studied independently and not as part of a prototype design and implementation project. Considering the fact that this research aims at developing more usable mobile cartographic interfaces for pedestrians following a UCD approach, a comparative evaluation of existing related research projects will give a deeper insight into their characteristics, objectives, methodologies and results. In doing so, possible issues raised by these implementations will be identified. Besides, this chapter will present several conclusions regarding the degree of research done on the issues, the appropriateness of the testing methodologies applied and the relations to this PhD research project.

The chapter starts with defining a number of characteristics that geo-mobile applications include and based on these, two comparison tables are made. The first one is for research prototypes and commercial geo-mobile applications with published research reports and the second one for commercial geo-mobile applications with no published research reports. Based on the first table, ten research projects are then evaluated and investigation is done on the methodologies followed, the issues identified and the parts still missing from current research. At the end, general conclusions are drawn regarding the current state of the art in geo-mobile applications and common issues identified.

3.2 Existing mobile pedestrian navigation applications

In order to select existing projects relevant to this research, some general considerations were taken into account: they should only use cartographic interfaces based on mobile device displays and the applications should be running on PDAs or smartphones and not tablet PCs or laptops. The environment they were developed to work in should be preferably urban areas and the type of users should not be persons with visual impairments or other disabilities.

After this pre-selection, a group of characteristics was defined, mainly based on the map aspects reported in Chapter 2. These characteristics were:

Release (year): the year when full reports about the prototype were published, or, in case of commercial applications, the year when the application (of the software version reported here) was released in the market.

1. Context awareness: the application takes into account the context of use and user to adapt the interface, the map contents or the way they are presented (see Section 2.2.2).

2. Type of user: the focus user for the application can be a pedestrian traveller in general (P) or a tourist in particular (T). Although more user types are noted in Section 2.4, only these two are of interest and related to this research. A vehicle driver (V) is also a common user (see Table 3.2) as most of the applications belong to car navigation systems.

3. User-based personalization/adaptation: the application considers the characteristics of the users, for example their age, to provide them with information related and (e.g. visually) adjusted to their particular needs. Personalization belongs to context awareness described in Section 2.2.2 but it is investigated individually here as it is an important contextual aspect.

4. Information overload consideration: the application restricts the amount of information supplied to the user, so that it can always be handled and understood properly. For example, if small photos of many different landmarks appear on the map at the same time, as what happens with the Google Earth desktop application, their legibility reduces dramatically. Visual information overload on maps is a problem of scaling and generalization which are discussed in Section 2.2.1.

5. Multimodality: The application can provide different types of information conveniently relevant to the user's mode of transport (e.g. walking, using the bus and so on). Providing route directions to pedestrians by just excluding highways in vehicle navigation systems is not regarded as multi-modality here. In these systems, although there is a pedestrian navigation mode very often, the map contents and visualization remain exactly the same and many pedestrian-reachable paths that the user could follow are not included.

6. Data provision method (online or offline): The application uses online (OL) information acquired from a remote server through a wireless data connection or offline (OF) information from the local data storage of the mobile device.

7. Route planning provision: the application calculates routes to one or more destinations and provides this information to the users helping them to navigate.

8. Use of landmarks or 3D buildings: the application shows landmarks (L) in a prominent form or in 3D format (B) on the map (see Section 2.2.5). These landmarks can work as reference points between the various sources of information available to the users of geo-mobile applications as it is discussed in Section 2.5.

9. Use of photos: the application provides the users with photos of places or landmarks in order to help them link reality, mobile maps and their mental maps as it is described in Section 2.5.

10. Map type (satellite, street map, thematic, topographic, 3D): the base map that the application uses is either a street map (STR), satellite image (SAT), topographic map (TP), thematic map (TH) or a combination of them. Another possibility is that the map is solely 3-dimensional (3D). For example, m-Loma in Table 3.1 is such an application.

11. Number of zoom levels or vario-scaling: the application has 1, 2 or multiple (ML) zoom levels. The zoom levels are regarded here as multiple when they are more than 3. Vario-scaling (V) according to Section 2.2.3.5 may also be used.

12. Smooth zooming capability: the change between different zoom levels is either step-wise or smooth, a technique described in Section 2.2.3.4.

13. Map orientation (North-up, heading-up or manual): the orientation of the map in the application is capable of presenting North-up (NU), heading-up (H) or both (NU+H). Depending on the situation and the user's individual preferences, in line with Section 2.2.4, either a North-up or a heading-up map could be more usable for the user. Manual map orientation (MN) is also possible when, for example, no positioning or orientation sensors are used but the map can be directly rotated by the user through hardware or software controls.

14. Map perspective (2-dimensional, 3-dimensional, egocentric, bird's-eye view or focus map): The mostly used map perspective used in geo-mobile applications is the 2-dimensional one (2D). 3-Dimensional (3D) maps are increasingly used as well. Bird's eye view (BV) is used to give the illusion of three dimensions to a 2D map. The above map types can be combined with an ego-centric (EC) view (see Section 2.2.4 and 2.2.5).

15. Following a UCD approach: the project followed a User-Centred methodology, as described in detail in Section 4.2 in order to create the application.
16. Published valid user testing: information regarding the evaluation of the application with users is available.
17. Type of application (prototype or commercial): the application is regarded here as a research prototype (PR) when it represents the outcome of a research project, or a commercial application (CM) when produced by a company or organization.
18. Project period: This is the period of time that the project lasted for.

Starting from 2002 as the year of release/publication, the projects were then put in chronological order in two tables. Table 3.1 shows some examples of research prototypes or commercial geo-mobile applications with published research reports and Table 3.2 the characteristics of a number of commercially available geo-mobile applications with no published reports available.

Release	Name	Characteristics																	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
		Context awareness	User type	User-based personalization / adaptation	Information overload consideration	Multi-modality	Data provision method	Route planning provision	Use of Landmarks or 3D buildings	Use of photos	Map type (N = no map used)	Number of zoom levels	Smooth zooming capability	Map orientation	Map perspective	UCD applied	Published Valid user testing	Research prototype / commercial application	Project period
2002	*REAL*	Y	P	N	N	Y	OF	N	N	N	TP	2	N	NU	2D EC+BV	N	N	PR	2001 - 2002
	Lol@	Y	T	Y	Y	N	ON	Y	Y	Y	TP+TH	2	N	NU	2D EC+BV	N	N	PR	2000 - 2002
2004	*GiMoDig*	Y	P	Y	Y	N	ON	N	Y	Y	TP+TH	ML	N	NU	2D	Y	Y	PR	2001 - 2004
2005	*m-Loma*	Y	P	N	N	N	ON	N	Y	N	3D	ML	N	MN	2D+3D	N	Y	PR	2004 - 2005
2007	*EGSSystem*	Y	T	N	N	N	ON	N	N	Y	TP+TH	ML	N	NU	2D	N	N	PR	2006 - 2007
	Navitime	Y	P	N	Y	Y	ON	Y	N	N	STR+TH+3D	ML	N	NU +H	2D EC+3D	N	N	CM	2006 - 2007
2008	*MAPPER*	Y	P	Y	Y	N	ON	N	Y	N	TP+TH	ML	N	NU	2D	N	Y	PR	2007- 2008

Table 3.1: Comparison table of different research prototypes of geo-applications and their characteristics.

Release	URL	Name	Characteristics																	
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
2008	1	*Agis Navigator v.2.0*	N	V,P	N	Y	N	OF	Y	N	N	STR,TH	ML	N	NU,H	2D,EC,BV	n/a	N	CM	n/a
2006	2	*Alturion GPS Prof. v.6.0*	N	V	N	Y	N	OF	Y	N	N	STR,TH	ML	N	NU,H	2D,EC,BV	n/a	N	CM	n/a
2009	3	*amAze v.4.5*	N	V,P	N	Y	N	ON	Y	N	N	STR,SAT,TH	ML	N	NU,H	2D,EC,BV	n/a	N	CM	n/a
2007	4	*Co-Pilot Live v.7.0*	N	V,P	N	Y	N	OF	Y	N	N	STR,TH	ML	N	NU,H	2D,EC,BV	n/a	N	CM	n/a
2007	5	*Destinator 7*	N	V,P	N	Y	N	OF	Y	N	N	STR,TH	ML	N	NU,H	2D,EC,BV,3D	n/a	N	CM	n/a
2007	6	*Google (mobile) Maps*	N	P	N	Y	N	ON	Y	N	Y	STR,SAT,TH	ML	N	NU	2D,EC	n/a	N	CM	n/a
2007	7	*Google Navigator*	N	P	N	Y	N	OF	Y	N	N	STR,SAT,TH	ML	N	NU	2D,EC	n/a	N	CM	n/a
2006	8	*iGo My way 2006 plus*	N	V,P	N	Y	N	OF	Y	N	N	STR,TH,3D	ML	N	NU,H	2D,EC,BV	n/a	N	CM	n/a
2008	9	*iGo My way v.8.0*	N	V,P	N	Y	N	OF	Y	L,B	N	STR,TH,3D	ML	Y	NU,H	2D,EC,BV,3D	n/a	N	CM	n/a
2008	10	*INAV i-Guidance v.*	N	V,P	N	Y	N	OF	Y	N	N	STR,TH	ML	N	NU,H	2D,EC,BV	n/a	N	CM	n/a
2007	11	*Netropa Intellinav v.3.0*	N	V,P	N	Y	N	OF	Y	N	N	STR,TH	ML	N	NU,H	2D,EC,BV	n/a	N	CM	n/a
2006	12	Maptech Memory Map	N	P	N	Y	N	OF	Y	N	N	STR,SAT,TP,TH	ML	N	NU	2D,EC	n/a	N	CM	n/a
2006	13	*Marco Polo Mobile*	N	V	N	Y	N	OF	Y	N	N	STR,TH	ML	N	NU,H	2D,EC,BV	n/a	N	CM	n/a
2006	14	*MioMap v.3.0*	N	V,P	N	Y	N	OF	Y	L,B	N	STR,TH	ML	Y	NU,H	2D,EC,BV	n/a	N	CM	n/a
2007	15	*MioMap 2008*	N	V,P	N	Y	N	OF	Y	N	N	STR,TH,3D	ML	N	NU,H	2D,EC,BV	n/a	N	CM	n/a
2009	16	*Navigon Mobile Navigator v.7*	N	V, P	N	Y	N	OF	Y	L,B	N	STR,TH,3D	ML	N	NU,H	2D,EC,BV,3D	n/a	N	CM	n/a
2007	17	*Nokia Maps (Smart2Go)*	N	P	N	Y	N	ON	Y	N	N	STR,TH	ML	N	NU	2D,EC	n/a	N	CM	n/a
2006	18	*Odyssey Mobile 4*	N	V,P	N	Y	N	OF	Y	N	N	STR,TH	ML	N	NU,H	2D,EC,BV	n/a	N	CM	n/a
2008	19	*OnCourse Navigator v.8*	N	V,P	N	Y	N	OF	Y	L,B	N	STR,TH	ML	Y	NU,H	2D,EC,BV,3D	n/a	N	CM	n/a
2005	20	*Pharos Smart Navigator (Ostia)*	N	V,P	N	Y	N	OF	Y	N	N	STR,TH	ML	N	NU,H	2D,EC,BV	n/a	N	CM	n/a
2005	21	*PocketMap Navigator*	N	V,P	N	Y	N	OF	Y	N	N	STR,TH	ML	N	NU,H	2D,EC,BV	n/a	N	CM	n/a
2007	22	*PocketWAW v.3.0*	N	P	N	Y	ON	OF	Y	N	N	STR,TH	ML	N	NU,H	2D,EC	n/a	N	CM	n/a
2006	23	*Route 66 Navigate 7*	N	V,P	N	Y	N	OF	Y	N	N	STR,TH	ML	N	NU,H	2D,EC,BV	n/a	N	CM	n/a
2006	24	Teletype GPS v.062006	N	V,P	N	Y	N	OF	Y	N	N	STR,TH	ML	N	NU,H	2D,EC,BV	n/a	N	CM	n/a
2006	25	*Tom Tom Navigator 6*	N	V,P	N	Y	N	OF	Y	N	N	STR,TH	ML	N	NU,H	2D,EC,BV	n/a	N	CM	n/a
2006	26	*Via Michelin*	N	V	N	Y	N	OF	Y	N	N	STR,TH	ML	N	NU,H	2D,EC,BV	n/a	N	CM	n/a

Table 3.2: Comparison table of commercial mobile navigation applications based on their characteristics. The numbers in the column "URL" refer to the numbered list of URLs at the end of the dissertation.

In these tables, Y always refers to “yes”, N to “no”, and n/a to “not available”. For example, whether or not UCD was applied for the development of a particular commercial application is most of the times information that is not available due to the absence of related published reports.

From the tables, some interesting conclusions can be drawn, such as the total absence of context-aware, personalized and adaptable commercial applications. Changing map colours for day and night use can be done in many of these applications not only manually but also automatically based on the time of the day. However, this is regarded here as a very minor aspect to be considered as context-awareness, having more to do with the safety of driving at night. The use of photos for landmarks and smooth zooming capabilities are also rare. As it comes to UCD, there is no related information available from the companies that produce these applications and no published results of any usability testing. The latter can be somehow explained in terms of manufacturing secrecy strategies followed by companies in order to protect the copyright and the unique technologies used in their products against their competitors. Outlining the characteristics of these applications is still valuable for this research, as it provides an overview of the common solutions and approaches applied.

3.3 Mobile pedestrian navigation research prototype applications

The seven projects of interest that were presented in Table 3.1 will be critically evaluated in order to acquire directions for further research. Table 3.1 also contains a commercial application (Navitime) about which a published report is available. Thus it is possible to evaluate it together with the other non-commercial, research project prototype applications.

3.3.1 Case 1: m-Loma

The aim of m-Loma or Mobile Location-Aware Messaging Application (Nurminen, 2006) was to create a mobile guide system for pedestrians based on photorealistic 3D representations of reality. The main hypothesis was that realistic 3D maps are closer to observed reality in terms of cognitive recognition of objects. As such, the map interface should be more user-friendly and satisfactory. Besides that, the system was designed to provide the users with location-based information answering textual queries, GPS-assisted 2D map navigation and allow for creating content and messaging assigned to any object or map point. Usual geographic questions of the users, such as “where is that?” or “what is that?” should be answered by pin-pointing objects and points on the map, as part of the expected system functionalities. Additionally, provision of alerts and advices regarding public transportation malfunctions supplied by up-to-date online databases or real-time feedback from other users should be supported.

In m-Loma, several methods and techniques for 3D model rendering, optimization of speed and accuracy of the representations, database architectures and software development for carrying out the required processes are studied. Landmarks, such as tall buildings, churches and statues are regarded as important features of the environment for navigation and orientation of mobile users. Thus, the researchers' target was to visually recreate any possibly salient object available. In order to increase the speed of processing and presentation of the 3D models in limited-resource mobile devices, a lightweight geometry method is used together with dominant colour texture selection techniques (Figure 3.1).

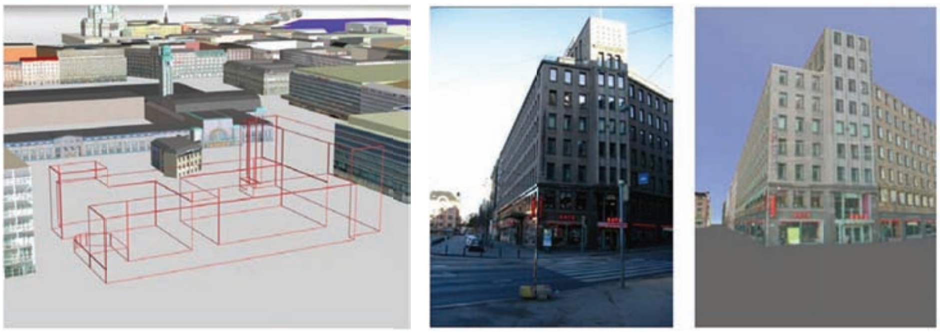


Figure 3.1: 3D modelling for mobile devices: lightweight geometry method (left) and comparison between a real building (middle) and its model in m-Loma (right) (Source: Nurminen, 2006).

In order to assess the functionality of the system, an initial user testing experiment was performed, aiming at investigating the way users orient themselves in reality and how they connect reality with 2D and 3D map representations on mobile displays. This was necessary for the creation of guidelines for the implementation of a user interface at a later stage of the research project (Nurminen, 2006). Eight test persons, one female and seven males, participated in the experiment. The testing methodology included several measures of performance, subjective estimations of workload, verbal protocols, video recordings and interaction logs. The test persons were asked to execute a series of relative pointing and navigation tasks, using both 3D and emulated 2D map views with a randomly selected starting map orientation. The 2D map was actually a 3D map shown only from above with no street names attached. Test balancing was archived by changing the order of tasks and route directions. After the experiment the captured logs and the videos were synchronised (Nurminen, 2008).

The results of the experiment showed that people are making use of prominent features in space, including facades, shape, colour, and size of buildings as well as landmarks. Whenever similarity of reality with the 3D representations on the mobile display was high, recognition and orientation could be done quickly. However, after users became familiar with these representations, they were getting lost and confused whenever a building was not presented accurately anymore. The researcher concluded that the development of more efficient and probably even automated systems for modelling of cities and the use of an efficient framework for the provision of lightweight 3D data to the mobile devices could increase the use of 3D model-based mobile navigation systems in the future

On the basis of the outcomes of the first experiment, several functions were added to the m-Loma prototype, such as the scripted action "View Landmark" to help users locate landmarks more easily. Another addition was the shifting of the viewpoint when the street view is rotated to provide a better image of the façades in front of the users. To evaluate the prototype improvements, a second field-based experiment with 16 male test persons, accustomed to 3D computer games, was carried out. The testing methodology and the user task formation was identical to the earlier experiment executed in m-Loma, except that the navigation tasks in 3D were initiated while the test person was on the direction of the target and the map in street-level view mode. In addition, an alternative navigation technique was available this time, named orbiting, where the direction of view was always locked on a target, so that the viewpoint was orbiting around that. At the same time, an arrow showing the direction of the target was displayed on the map. However, no routing information and GPS positioning was offered. Often, the test person had to spend some effort in the beginning of the tasks, locating himself in 3D before continuing the task execution. As it comes to the 2D map used for the tasks, a different approach was followed compared to the first experiment. This time a touristic map was used, made by professionals, which included landmarks and street names (Nurminen, 2008).

The results of the second experiment demonstrated that the performance of the test persons as well as their focus on the tasks was improved after applying the new technical solutions compared to the first one. Feedback for possible improvements was again gathered, suggesting for example a rotation of the map in the direction of the favourite landmark of the user when the "View Landmarks" function is activated.

A very important finding of the experiment was the overall faster task completion times using a 2D map instead of a 3D one, in contrary to the previous results. Considering that the 2D map used in the second experiment was of much better design, Nurminen (2008) stresses the importance of map representation and its influence on the users' performance. Finding street names on a 2D map proved to be a simple and direct strategy for linking reality to the mobile map when navigating compared to the less efficient cue selection on the 3D map. On the other hand, local orientation using street numbers was not very efficient on the 2D map due to its poor relation to reality. But again, small-scale cues were also missing from the 3D map many times, making local orientation difficult as well.

The use of any type of GPS positioning, magnetic orientation sensing, route provision or alternative methods and techniques for user guidance was abandoned in the prototype of m-Loma. The reason for that decision was to avoid GPS accuracy problems which could affect the functioning of the prototype and at the same time to direct the users' focus on the advanced solutions applied. However, through the experimental evaluation of the prototype, the necessity of using guidance support techniques was clearly assured.

3.3.2 Case 2: REAL project

The REAL project (Baus et al., 2002), was a research focusing on the design of a limited-resource hybrid mobile pedestrian navigation system adaptable to multi-modal and multi-sensor environments. Thus, smooth adaptation to different transport modes had to be feasible without noticeable disturbance of the mobile user's activities.

The developed system integrated three main components: a desktop workstation capable of 3D graphics presentation and able to provide virtual walk-through in the environment; IRREAL, an infrared-based indoor positioning and information retrieval module using a mobile device (Palm); ARREAL, an outdoor pedestrian navigation system mainly utilizing a GPS receiver, a magnetic orientation sensor and a subnotebook with an on-glass attached display used as a map interface, capable of presenting sketch-like ego-centric and bird's-eye view perspectives of the map (Baus et al., 2002).

The bird's-eye view is used to provide the user with an overview map of the area around him or her, while the ego-centric view is used when more detailed information is needed. Additionally, the system is able to present textual information on the map, such as the names of streets or buildings which are visible from a particular viewpoint of the user, or instructions for navigation in the form of next-turn arrows. Transformation from bird's-eye to ego-centric views is also dependent on GPS accuracy and walking speed. GPS positioning accuracy is presented in the form of a dot (circle) on the map: the circle is larger when the accuracy is low and smaller when the accuracy is high. When GPS accuracy is high, more detailed information is presented on the display, and when the user is walking faster zooming out is applied to the map. The reason for that is to avoid the displaying of information about buildings at the boundaries of the display, which would make this information continuously disappear and re-appear as the user is moving fast (Baus et al., 2002) (Figure 3.2).

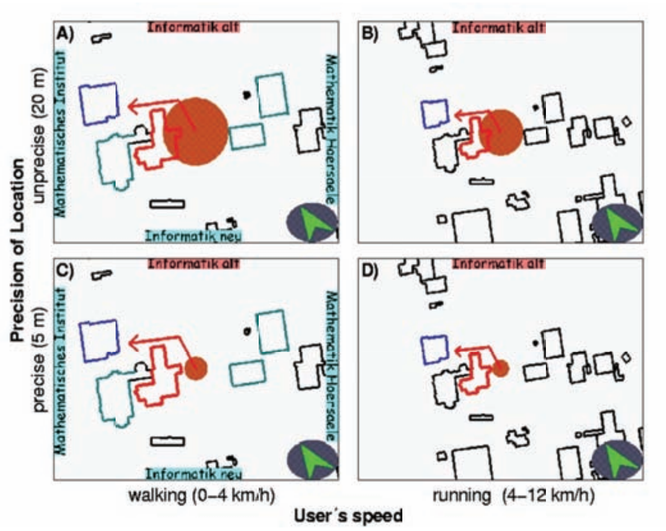


Figure 3.2: Adaptation of mobile map based on positioning accuracy and moving speeds (Source: Baus et al., 2002).

3.3.3 Case 3: EGSSystem

Beeharee & Steed (2007) investigated the use of geo-tagged photographs of buildings in pedestrian navigation systems through the implementation of a system named EGSSystem (Enhanced George Square system). George Square is in Glasgow in Scotland. Their hypothesis was that current mobile navigation applications, providing the users with route instructions and location-based information about buildings and places, may often introduce two problems. These are the difficulty of direct relation of the presented information forms to reality, and the system's inability to deal with the significant contextual parameter of visibility of spatial features from the user's current position. An example of the first problem is when route knowledge is acquired through instructions that demand interpretation and evaluation actions from the user's side. In this case, conceiving relative distances is something that may be cumbersome for the users.

Aiming at building an application for guidance into urban areas that makes use of the real world's structural knowledge, a prototype was implemented, following the common functioning of pedestrian navigation systems. Thus, the user's location and movement in space was continuously traced on a mobile map interface, while at the same time the user was provided with icons linked to georeferenced and contextually specific information. The position of the user could be determined through a GPS receiver or entered manually, and according to his or her movement several links and media resources that could be useful were presented to him or her. Photographs of reality were among the essential resources provided (Beeharee & Steed, 2007).

One of the principal aspects of the research was to attach information to polygons rather than spatial coordinates and filter that information (whenever retrieval is needed) depending on the visibility of the polygon from a particular position. Following this approach, the researchers aimed at overcoming possible issues of inaccuracy and inconvenience when information is simply linked to spatial positions (Beeharee & Steed, 2007).

Considering visibility in order to recall information, the researchers expected that the data provided to the users could be assigned more smoothly to their real world activities. Additionally, the EGSSystem on which the prototype was based incorporated the innovative function of generating recommendations of information to the users not only by estimating adjacency of the user to the information carrier, but also inspecting relevance of context by analyzing the use of past recommendations. This function is offered by the Recer Service component. The EGSSystem diagram during runtime performance is shown in Figure 3.3, where the flow of location data and recommendations between the different components and tools is indicated. In the same figure a screenshot of the actual implementation is presented, where polygons are highlighted based on their visibility to the user and the type of information attached is represented by corresponding icons (Beeharee & Steed, 2007).

Although two are the main sources of information for the EGSSystem, the map and the focus databases (the second containing polygonal regions), the user is allowed to also create polygons or select existing ones and attach URL and photo links to them. Besides, the user can also enter information for polygons that are visible in the photos shown. All these functions are done through the Editor Viewer tool. With icons, the user can determine the location from where the photo was taken, as well as the capturing direction and angle, including the view area volume. The GPS receiver could possibly be applied to support the automation of these functions in a future implementation.

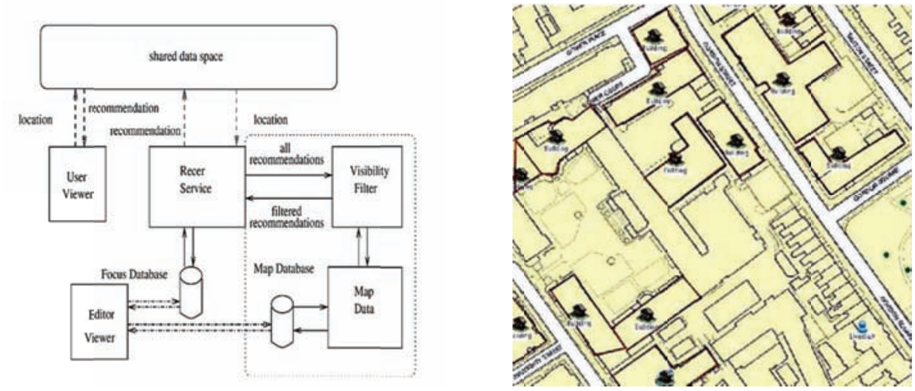


Figure 3.3: EGSSystem diagram (left) and example screen of the system showing highlighted polygon boundaries and resource type icons (right) (source: Beeharee & Steed, 2007).

Using the information collected with the User Viewer collection tool, focus boundary visibility can be computed using a raycasting algorithm which was selected due to its simplicity of implementation. In fact, the concept of attaching information to polygons allows also for the retrieval of information associated to polygons when the user is in a location where these polygons should be visible (Beeharee & Steed, 2007).

In order to test the actual functionality of the system a prototype was adapted to Bloomsbury area in London, United Kingdom. Beeharee & Steed (2007) argue that the system can be technically adjusted and used in any place in the United Kingdom. This is possible as far as a map of that area can be delivered through OS Master Map.

In the Bloomsbury area experiment, 30 local photographs were captured and uploaded on a web page, which were then imported in the map and linked to buildings through the EGSSystem. Then a laptop and PDA-based informal testing in the field was performed, with the latter making use of a Wi-Fi data connection to the database server. The test persons were asked to walk in Bloomsbury's streets and when a photo of a building was recommended based on their location, they were asked to try to recognize that building in the environment (Figure 3.4). The problem was that a photo may originally have been captured from a different angle, but the results showed that the recommendation of photos depending on their visibility as a means of navigational support is easy to comprehend. The users were quite able to recognize the buildings from photos taken from any direction, and the observed confusions may be addressed by modifying the system in the future to check the visibility of particular parts of the buildings (Beeharee & Steed, 2007).

Figure 3.4: A test person interacting with the prototype application (left) and acquiring a photo from the server by clicking on a photo icon on the map (middle and right) (source: Beeharee & Steed, 2007).

There is no detailed information available regarding the number of test persons, the methods of observation and analysis used and the experimental settings.

3.3.4 Case 4: Navitime

Realizing that there was no existing research on the influence and issues coming from the use of context-aware pedestrian navigation applications by a large base of users, Arikawa et al. (2007) decided to inspect Navitime (URL28), a commercial application / service running on mobile phones. This application has been developed and supplied by the Japanese cellular service provider NTT DoCoMo (URL36). The number of (Japanese) users of the service reached 1.82 million in January 2007 and it was continuously rising thereafter. The main idea of the researchers was to investigate the expertise needed from people when trying to link reality and knowledge in digital form through mobile systems in order to find and make proper use of the provided information.

Together with several other cities in Japan, Tokio, the most populated city in the world with over 30 million inhabitants and a broad rail system, constituted the context of the study in terms of culture and geographic area. Considering that Navitime users use a navigation application for pedestrians mainly based on a GPS receiver, the accuracy of positioning of the mobile phone becomes a major issue with respect to usability. At the time of study, GPS positioning accuracy ranged from 10 meters in obstacle-free areas to 3 meters using map-matching methods but it worsens in dense urban areas. In case of such "urban canyons" or at indoor places where the GPS signal is weak or absent, an alternative positioning technique based on cell tower location estimation can be used (see Section 5.5, technical feature no.1), with less than a few hundred meters accuracy (Arikawa et al., 2007).

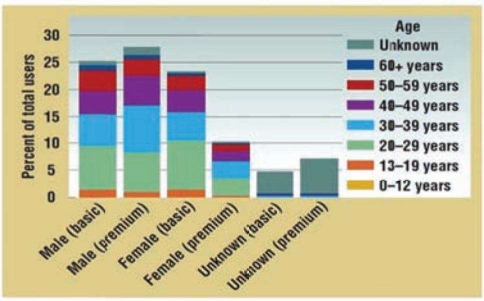
Navitime is an application that follows a “total navigation support” approach, where different transport modes such as walking, using public transportation or driving are supported, providing the user with optimum routing recommendations in an interactive way. In order to improve the services offered by the application, its developers rely upon their own every-day experience with Navitime, evaluating at the same time the access records of the users.

Quick response to interactive searches and computation of routes is one of the requirements that users have from this type of application, but they are limited by the computation power of mobile devices. Therefore, a server-client approach has been followed involving the provision of information in different forms (maps, downloadable information, voice alerts and so on). In this way, even complex route calculations estimating several parameters such as travel expenses, distances or number of transfers, can be done fast and four alternatives can be provided to the user. Concerning the selection of the most convenient one, support information is also served to the user, such as current weather conditions or CO_2 production. Additionally, minor context-aware adaptation of the interface is performed, depending on the patterns of use and the capacities of the system at a particular moment (Arikawa et al., 2007).

The pull-based information retrieval in Navitime involves several strategies such as location search based on keywords, telephone numbers or area codes, bookmarked or simply past locations, hierarchical location lists, captured 2D barcodes (in some printed maps) and speech recognition. Push-based provision of information to the users is considered problematic by the developers of the application, as location alone cannot determine the actual activities and needs of the users. Using multi-media presentation techniques, the developers tried to improve the effectiveness of the system and the user’s confidence in it. For instance, when someone exits a rail station and initiates route navigation, a 2D mobile map poses difficulties of orientation. Thus, a 3D representation is used (Figure 3.5), although the mobile network infrastructure may reduce the usability of this approach as a result of slower than required data transfer speeds (Arikawa et al., 2007).

In order to investigate the influence of the system on the pedestrian users, Arikawa et al. (2007) executed a preliminary user research with two graduate students, both males. They also took into account statistics on demographics and use of the system obtained by NTT DoCoMo. In Figure 3.6, (a) the age distribution of the current system users as of February 2007, (b) route selection criterion percentages, (c) comparison of popular destinations for car and pedestrian navigation systems respectively and (d) the time distribution of most favoured local searches are presented.

Figure 3.5: Switching from 2D to 3D representations in Navitime in order to support orientation of the user when exiting indoor transportation stations (source: Arikawa et al., 2007).



(a)

Route selection criteria	Percent of users
Minimum travel time (default)	91.80
Minimum travel expenses	4.50
Minimum number of transfers	2.40
Minimum walking distance	1.30

(b)

Pedestrian navigation	Car navigation
Train or subway stations and airports	Expressway interchange
Universities and colleges	Ski and snowboard resorts
Hotels	Amusement and theme parks
Post offices	Local government offices
Manga café	Shopping malls and districts

(c)

Weekday (12 a.m.–5 a.m.)	Weekday (6 a.m.–11 a.m.)	Weekday (12 p.m.–5 p.m.)	Weekday (6 p.m.–11 p.m.)
Parking lots	Banks, credit unions, and ATMs	Banks, credit unions, and ATMs	Miscellaneous Japanese-style pubs
Banks, credit unions, and ATMs	Parking lots	Train or subway stations and airports	Banks, credit unions, and ATMs
Train or subway stations and airports	Train or subway stations and airports	Parking lots	Train or subway stations and airports
Bars, pubs, and nightclubs	Covenience stores	Covenience stores	Parking lots
Covenience stores	Hair, makeup, and beauty salons	Hair, makeup, and beauty salons	Ramen (noodle soup) restaurants

Weekend (12 a.m.–5 a.m.)	Weekend (6 a.m.–11 a.m.)	Weekend (12 p.m.–5 p.m.)	Weekend (6 p.m.–11 p.m.)
Parking lots	Banks, credit unions, and ATMs	Banks, credit unions, and ATMs	Miscellaneous Japanese-style pubs
Hotels	Parking lots	Parking lots	Parking lots
Bars, pubs, and nightclubs	Train or subway stations and airports	Train or subway stations and airports	Banks, credit unions, and ATMs
Train or subway stations and airports	Hair, makeup, and beauty salons	Ramen (noodle soup) restaurants	Train or subway stations and airports
Banks, credit unions, and ATMs	Ramen (noodle soup) restaurants	Miscellaneous electric appliance and PC shops	Ramen (noodle soup) restaurants

(d)

Figure 3.6: Demographic data of Navitime users (February 2007) obtained by NTT DoCoMo cellular service provider (Arikawa et al., 2007).

The age of the two test persons involved in the experiment was 25 and 26 years. They were unfamiliar with the application and they had a different level of familiarity with the Tokyo test area. Both test persons carried out a task involving reaching a subway station by foot, taking the train to a next station and then walking to a particular restaurant, spending thirty to fifty minutes in total. The test persons were observed by two researchers who were following them, asking them short investigative questions whenever they were locating something noticeable in terms of user – environment interaction (Arikawa et al., 2007).

Using a think aloud protocol and a mobile audio recorder, an insight into the user experiences was captured, backed up by an interview session at the end of the tasks. For example, the test persons were trying to link the mobile map and reality in order to understand where they are and what was the correct direction to walk to, especially when exiting the subway. At the same time, they both had the impression that by continuously using the mobile device they may have missed acquiring fundamental information from the real world. However, Arikawa et al. (2007) admit that the use of two test persons only in their field-based experiment could not result into any statistically valid conclusions.

By combining the results of their preliminary and experimental studies, demographic and use statistics, unofficial researcher – user discussions and existing literature, the researchers made the following assumptions regarding Navitime:

First, more context-aware interactivity is needed, but without increasing the complexity of the systems for the users. Second, the profits coming out from the use of it increase as the user becomes more familiar with the application. Third, navigation in unfamiliar environments is helped by using the application, as it can compute up-to-date transportation and traffic information from different sources and propose optimal routes. This is probably impossible to be done by a human being alone. Fourth, on-trip modification of route parts to fit users' needs for visiting particular points of interest found via the local searching function is possible. Fifth, the use of the application may create dependencies and lead to avoidance of impulsively selected routes as well as produce the opposite result, a sense of security that allows for spontaneous sight-seeing activities and discoveries of new places. Sixth, privacy regarding the user location is a critical issue, calling for balanced solutions between provision of collaborative location information to anyone and protecting the individual user's privacy. Seventh, there is a difference between men and women in terms of mobile pedestrian navigation systems use, although the researchers indicate that there is a lack of extended user data analysis in order to be able to explain this statement in detail (Arikawa et al., 2007).

In the end, Arikawa et al. (2007) discuss the difficulties of creating multi-cultural and multi-regional navigation applications, as when, for example, translation of local place names to different languages is needed. In addition, they report that user-generated content should be efficiently used in order to prevent overload of information, and indicate that it should be considered what would be the effect of using various pervasive technologies on the behaviour and everyday activities of people.

3.3.5 Case 5: Lol@

Local Location assistant, or LoL@ (Umlauft et al., 2003) was a project initiated in 2000 by the Telecommunications Research Centre of Vienna, aiming at the study of location-aware multimedia mobile applications for UMTS (Universal Mobile Telecommunications System). In this context, a prototype application was developed in the form of a mobile tour guide dedicated to tourist visitors of the city centre of Vienna.

Amongst the capabilities of the application was the provision of predetermined routes, POI information, navigation support and route planning, interaction in multimodal ways and a digital tour diary. The presence of a tour diary was considered to be very important by the researchers, taking into account the usual loss of memories and evidence regarding travelled places when there is no immediate recording and filing of trip-related information (routes, photos, visited places and so on) (Umlauft et al., 2003).

The implementation of the prototype of Lol@ was based on previous literature regarding the needs and behaviour of tourists and navigation systems. Umlauft et al. (2003) defined tourists as persons with a good education level who spend a weekend in the city as an extension of a business trip and who would like to do a sight-seeing on foot without previous planning. Lol@ can be used as an interactive alternative to a printed travel guide.

Using server-client mobile network architecture through UMTS or GPRS connections, the prototype could overcome some of the constraints of the mobile devices, especially regarding the computation performance. For that reason, a persistent data connection was required in Lol@, as all the data were stored in a server database. However, at the same time no data exchange was occurring between the application and the server for simple interactions that did not demand newer information from the application’s side. In this way, network traffic was reduced and time response increased.

As it comes to the interface design, the constraints of mobile devices were regarded, including the small display sizes, keyboards, and the influence of the environment. The researchers note that presenting information on mobile displays is not feasible in many cases in view of the display size and scrolling is not comfortable either. Hierarchically organizing information could therefore be a convenient approach, but bigger requirements of the short-term memory of the users would then be necessary (Umlauft et al., 2003). The application interface colour scheme becomes very important in real contexts of use, where conditions of the environment, such as strong sunlight, and the user's limitations, such as visual impairment or colour blindness can reduce the usability of the application (Umlauft et al., 2003).Clear design of icons and menus was the approach suggested by the researchers who indicate that, in addition, the interface language could be set manually by the user or even automatically using the mobile phone's SIM card default language setting.

The fact that the user is mobile and, therefore, in a possibly stressful situation where information retrieval is urgent, requires careful interface design directions (Umlauft et al., 2003). The map metaphor was one of the selected fundamental forms of communication with the user and was considered appropriate for an application that should be effortlessly learnable and directly functional. The application provided the user with a map of the city centre of Vienna allowing for two levels of zoom, an overview and a detailed one. Besides, hypertext and multimedia content was offered through information windows and server-centric voice recognition was enabled as an alternative user-application interaction technique. Umlauft et al. (2003) argue that voice recognition-controlled interfaces can perform better than traditional touch-based graphic interfaces in terms of usability and readiness, as current mobile devices have limited user input capabilities.

The idea of a multi-mode application was generally rejected, as according to Umlauft et al. (2003), the user pays more attention to the observation of the environment than interacting with the application. As a result, the last state of the application may be forgotten before the user returns his / her attention to it.

While POIs were simply symbolized for cluttering prevention and categorized under regions of interest in the overview map, particular POIs and street names were presented in the detail map. Dedicated symbolization was applied to the most significant touristic places and category symbolization, defining the type of POI, to the less significant ones. On the map, the position of the user was represented by a gradually fading colour circle with a size inversely correlated to the accuracy of the position estimated by the system (Figure 3.7). A similar solution was applied in the REAL project prototype presented in Section 3.3.2.

The Developers of Lol@ did not make use of contextual aspects, as for example the user's current location, for adapting the map or triggering particular application responses. Only selecting and pointing out a default POI based on the position of the user was facilitated.

Figure 3.7: Displaying the user's position and the estimated positioning accuracy on the mobile map (source: Umlauft et al., 2003).

In order to implement a usable prototype, three scenarios of use were formulated. A "Walk Through the City Scenario, a "Hotel Room Scenario", where planning of the tour is performed beforehand by the tourist and an "Accessing Information From a Desktop PC Scenario". In the first scenario, a mobile map becomes the centre of attention. After the user was selecting one of the offered tour routes (Figure 3.8 a, b, c), an overview map depicting the entire route together with several POIs belonging to particular regions of interest was provided (Figure 3.8 d). By clicking on any region of interest or POI, information pop-up windows regarding this region were provided (Figure 3.8 e, f, and g).

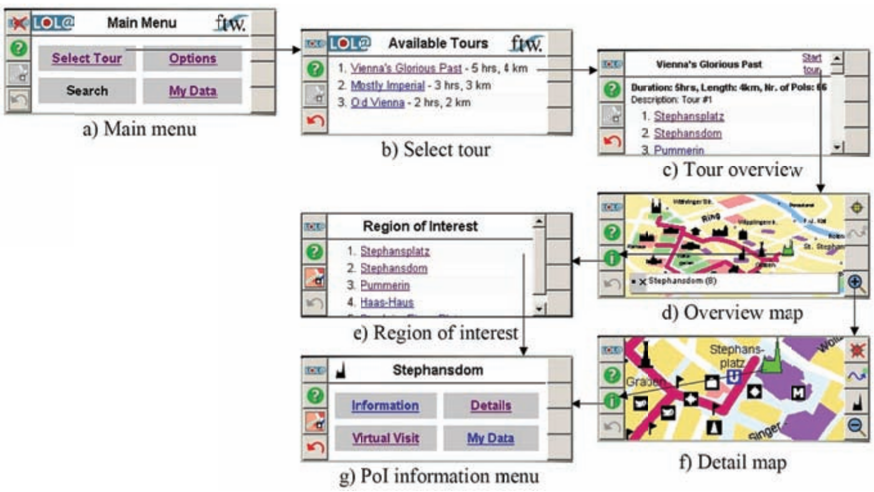


Figure 3.8: Interface menu structure and different map views of Lol@ (source: Umlauft et al., 2003).

In the "Hotel Room Scenario", the user can preview and make a planning of the tours that are preferred, including selectable multimedia information provision regarding involved POIs and virtual tours. User interests and profiles, observed actual user behaviour and other user suggestions could be acquired in a next version of the application in order to filter the information provided. Extensive context awareness was also suggested to be applied, as by checking, for example, whether a museum is open at a particular time in order to execute route calculation (Umlauft et al., 2003).

The user could use the zoom function as well in order to inspect the detail map, or enable the positioning system. In navigation mode, when guidance for travelling from a recent position towards a succeeding POI or any other point on the map is provided, the detail map was also shown on the display. Any POI that was already visited was automatically inserted into the tour diary, while at the same time the user could attach remarks or personal data including photos captured. The user was asked to affirm the arrival at any POI or route part, and this information was cross-checked with the position estimation of the application. If there was any discrepancy between the two, taking into account the positioning tolerance of the system, a street-name based confirmation procedure initiated.

Landmarks were also used in order to support the understanding of the route by the user. For that reason, additional information, such as textual descriptions and photos, was provided on-demand for the landmarks along the route (Umlauft et al., 2003).

Although user research was proposed by Umlauft et al. (2003), the results of such research have not been published.

3.3.6 Case 6: MAPPER

The MAPPER (MAP PERsonalization) application was the result of an effort to address the issue of map information overload on mobile device displays used in real contexts (Weakliam et al., 2008). Considering the physical and connectivity limitations of mobile devices and their negative effects on human-computer interaction, the researchers decided to develop a preference-based personalized map generation solution. In reference to the hypothesis that users of mobile maps should be provided with the minimum possible amount of information in order to be able to efficiently make use of it, map content can be reduced according to the particular needs of the users.

At the same time, Weakliam et al. (2008) argue that acquiring user preference information solely through manual input from the users whenever they need to obtain a map and while they are mobile, may prove inefficient, as it would require a large amount of time and effort. Dynamic profiling, an evaluative processing of user acts and behaviour aimed at detecting their interests dynamically and inevitably, could alternatively be used in this case (Weakliam et al., 2008). Adapted from desktop web browser evaluation methodologies where user interactions are captured through the interface, dynamic profiling can be applied into mobile map browser environments as well. Using this approach, dynamic modelling of user preferences is possible, allowing for a reduction of data needed for map rendering or, in other words, the personalization of the mobile map. The easiness of carrying out tasks with the use of mobile maps is consequently increased as the user is provided with task-focused content (Weakliam et al., 2008).

In the MAPPER application two levels of map personalization are delivered, a layer- and an individual feature-based one. The first involves provision of every feature available in the chosen map layer(s) and the second additionally offers individualization of the content. For example, if a user is only interested in inspecting the hydrographic features of a particular geographic region, only the rivers, lakes, reservoirs and the like are presented on the map. Further, if he/she only prefers to look at specific features in the same layers, for example lakes of a size larger than a favoured value, the map content alters accordingly (Weakliam et al., 2008).

Many of the widely available mapping applications, such as MapQuest (URL32), create and provide the users with static raster maps. These raster maps cannot be personalized easily, in view of the fact that separation of map features into individual layers is not possible (Weakliam et al., 2008). The researchers add that superimposition of particular layers on the top of the background raster map is possible anyhow in some cases, but this still does not allow for map data reduction or personalization. In contrast to this, vector data-based map creation has many advantages, such as bigger interaction capabilities, lower transmission costs due to the smaller data size and a division of maps into landmark and non-landmark layers. Landmark layers, consisting of points and polygons, typically outline the attention of users during tasks, for example when the users attempt to spot the location of the closest airport. Non-landmark layers, consisting of lines, are principally used for navigation through maps (Weakliam et al., 2008).

According to Weakliam et al. (2008), every time a new user uses MAPPER, a default map and map content are provided, as there is no recorded user preference data available yet. Any interaction of the user with the map thereafter is captured and the extracted information is stored in a newly made user profile in the form of log files. These log files are transferred to the server for further processing after each user session is over, because the computational power of the mobile device is too low for this task. Using the profile data and any previously made user specific requests, personalized map content is provided to her/him the next time he or she uses the application. The user interactions that are captured in order to be analysed by the application are the fundamental map browsing actions of zooming, panning and layer toggling and highlighting (Weakliam et al., 2008). These actions are categorized into weak and strong ones, depending on the quality of information regarding the interests of the user that they can provide. In the course of a session with vector maps, the information captured is related to the type of action performed, map content on which the action was performed, time needed for performing the action, map frame boundary created by the action and intersecting map layer and feature frame. In the end, a data mining technique similar to the one used in market trend analysis is applied to sort out the trends of layer use from the users and for grouping the users depending on their interests. There is also a separation between long and short-term preferences of the users, with the first linked to non-landmark layer use and the latter with landmark layer use (Weakliam et al., 2008).

The general system diagram is shown in Figure 3.9, where the flows of data between the client (a tablet PC) and the server are drawn as described earlier. Although the research presented in this dissertation limits itself to applications running on PDAs and smartphones, MAPPER is studied because of the planned migration of the application to mobile device platforms.

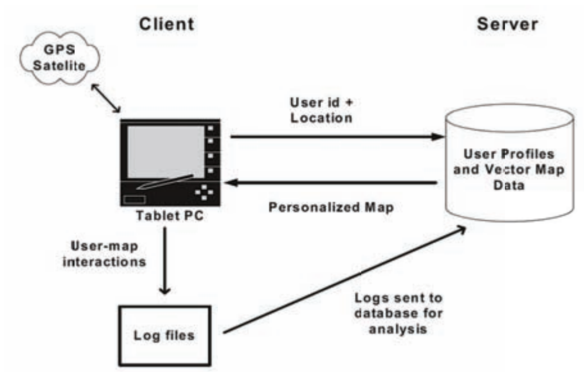


Figure 3.9: MAPPER general system diagram (Weakliam et al., 2008).

Based on the results of previously executed user experiments, the researchers argue that layer-level map content personalization shows an increased efficiency and easiness regarding the task execution by the users. In order to investigate the hypothesis that similar benefits can be obtained when personalization is performed on both layer- and feature-based map content, a user study was executed. Six test persons, half of them familiar with MAPPER and half not, were given various mapping tasks to be completed within one month. There was no limitation in the way the users could interact with the maps and explore them, as long as each of the tasks was completed. After the end of the experiment the personalized maps were returned to the researchers for analysis. The results, shown in Figure 3.10, demonstrated that the required data size for personalized map creation was substantially smaller than the one needed for non-personalized ones. Besides, the number of user inquiries for supplementary layer content was reducing while they were completing more tasks, showing a successful provision of adequate user and task-related content by the system (Weakliam et al., 2008).

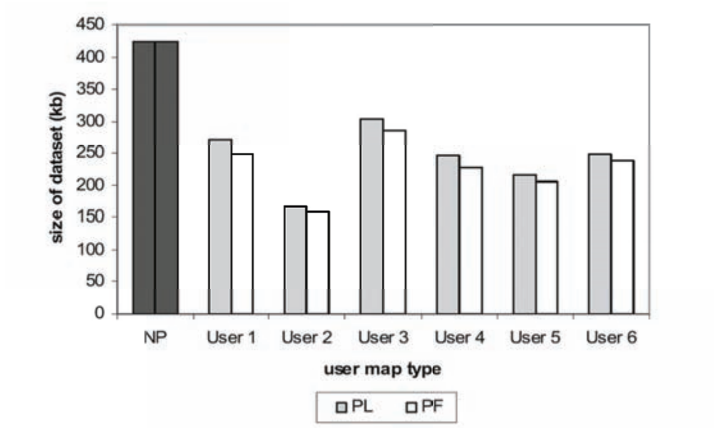


Figure 3.10: Comparison of the dataset size used for the rendering of a non-personalized map (NP) with the ones required for the rendering of personalized maps at Layer- (PL) and Feature- (PF) level by the test persons (source: Weakliam et al., 2008).

There now is a plan for developing a mobile device (PDA or smartphone) version of MAPPER, including all the current application functionalities. For that, more thorough user-based studies should be designed and executed, involving functionality evaluation of the system in both quantitative and qualitative manners. Based on the analysis of the results of these tests the efficiency of MAPPER could be further improved.

3.3.7 Case 7: GiMoDig

GiMoDig (Geospatial info-Mobility service by real-time Data-integration and generalization) was a multi-disciplinary EU-funded project initiated and managed by the Department of Geoinformatics and Cartography of the Finnish

Geodetic Institute (Sarjakoski & Sarjakoski, 2005). The project focus was on the improvement of both interoperability and accessibility of primary topographic databases of different countries managed by National Mapping Agencies. In view of that objective, the main aim of the project was to develop real-time generalization and data integration methods and techniques for transferring data from these databases primarily to mobile users. To meet that aim, considering also the limitations of mobile devices in displaying maps due to their small screen sizes, a prototype geo-mobile application was developed and its usability was assessed. Although GiMoDig encompassed various research sub-projects coping with issues such as the heterogeneity between different national geo-databases, the interest here is on the prototype design and testing methodology followed.

The GiMoDig prototype constituted a server / client-based mobile location-based service providing the users with dynamic cartographic representations adapted to the users' preferences, requirements and the context of use. To make these representations easily comprehensible at any zoom level used, several guidelines for small-display cartography were established. For example, when different map symbol layers are put on top of each other, text objects should always stay upon them (Sarjakoski & Sarjakoski, 2005).

In the GiMoDig project, several methods and techniques for real-time map generalization were investigated and later developed, making use of Multi-Representation Data-Bases (MRDB) for storing pre-generalized data of various detail levels. The aim of those was the reduction of complexity for the provision of adaptable, personalized maps-on-demand, according to the requirements of the users and the context of use. Apart from map generalization, a plethora of innovative and advanced methods for cartographic visualization were implemented, such as progressive vector data transmission / update, vario-scale presentation (see Section 2.2.3.5) and real-time placement of labels and icons to avoid cluttering (Sarjakoski & Sarjakoski, 2005). In Figure 3.11, an example of the latter is illustrated.

Usability of the product design was one of the main considerations in the GiMoDig project, thus the course of design and development activities for the prototype was based on UCD. Starting with a survey of related mobile services and a classification of the potential end-users of such a system in line with the objectives of the project, the user requirements and the (real) contexts of use were identified (Nivala et al., 2005). To do so, different domains of usage that a working prototype could serve were distinguished during the requirement analysis, as, for instance, information services, military support and navigation. In these domains the different needs and expectations of the end-users were categorized as: personal location identification, identification of a person's location by others, identification of location of others, object location identification, guidance obtainment, information retrieval and help acquirement (Jakobsson, 2002).

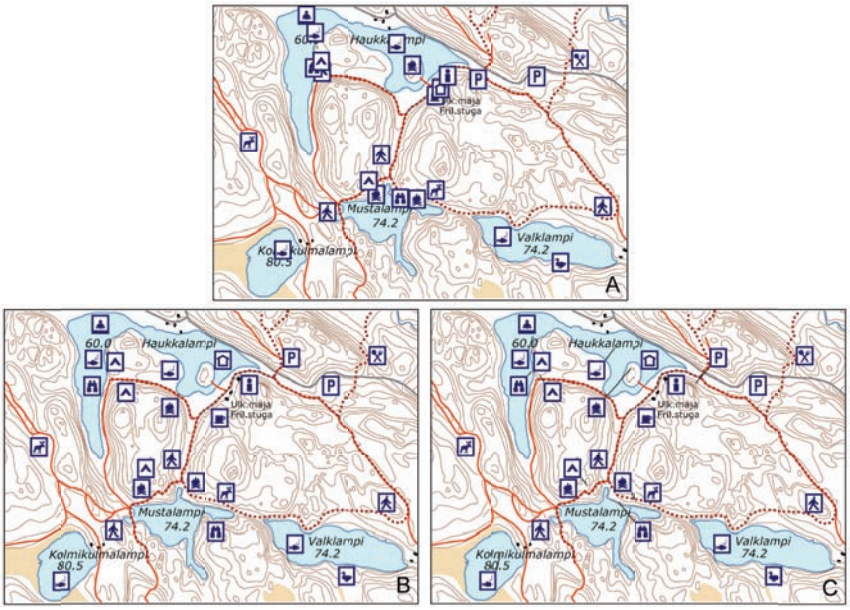


Figure 3.11: Example of real-time icon placement in GiMoDig: A) original map with POI icons, B) icon placement performed and C) icon placement performed, with added lines referring to the original icon positions (Sarjakoski & Sarjakoski, 2005)

In light of the above findings, twelve different scenarios of use (and their corresponding use cases) were composed, illustrating aspects of the service the prototype would provide, which would be beneficial to the users. As the usage domains indicated in the scenarios had many identical characteristics, four out of the twelve use cases were chosen as suitable for representing the capabilities and technical aspects of GiMoDig and were investigated further. These use cases were: a) hiking in Nuuksio national park (representing outdoor activities), b) a fire at the University of Hannover (representing an emergency instance), c) border crossing between Denmark and Germany by bicycle and d) expert use of the GiMoDig server-side geospatial data management system. The first use case served as a research ground for studying the context of use and the related basic user requirements, by conducting a pilot field-based experiment. The aim of that experiment was not only to identify the preliminary user requirements, but also the usability problems of existing topographic maps when presented on mobile devices. The testing methodology consisted of observation, interviews, audio and (partially) video recording. During the test sessions, the participants were given a PDA where topographic maps were shown, and they had to execute a series of tasks while being observed by two researchers. The experiment is detailed in Nivala & Sarjakoski (2003). The number of test persons and their demographics are not reported. Taking into account the outcomes of the experiment, preliminary design guidelines and four main usability goals for the GiMoDig prototype were formed (Nivala et al., 2003).

The first usability goal for the end-users in GiMoDig was to design an intuitive interface, simple and easy to use, in an effort to address the experimentally discovered problems with current navigation systems. The second goal was to provide cartographic representations suitable to the context of use and the different displaying devices used (PDA or laptop PC). Considering the difficulties that the test persons had in understanding the map symbols used in current geo-mobile applications, intuitive pictograms had to be made for the POIs. These should be easily perceived without the need for a legend. The third goal was to integrate topographic datasets from various databases as well as location-specific additional information which could be superimposed on the map. The presentation of this diverse information had to be smooth and compatible with the user's preferences. And finally, the fourth goal was to create adaptable, context-aware (and thus more usable) topographic maps for mobile devices (Nivala et al., 2005).

The users' needs and requirements with respect to technology were also considered carefully during the requirement analysis phase in the GiMoDig project and they were obtained through organizational meetings. Amongst these requirements, translated into service quality goals, were the compliance to the Web Map and Web Feature Service interfaces (WMS and WFS), the qualities of real-time data generalization and integration and the service availability (Nivala et al., 2005).

The development of the GiMoDig prototype was based on the principle that its design should address the requirements of the users in particular tasks. Thus user feedback was continuously collected on every new version of the prototype, starting with mock-ups and ending up into a working software prototype. This feedback was used to update the requirement analysis findings. The methodology used for evaluating the early prototypes comprised of iterative heuristic and expert assessment as well as usability and intuitivity testing. This process was followed until the prototype fulfilled the user requirements, limited by the main research aims of the project (Sarjakoski & Sarjakoski, 2005).

An example of the adaptive maps provided by the GiMoDig service, in line with the use case of hiking in Nuuksio national park, is shown in Figure 3.12. In this example, the season of the year, the user's activity and his or her profile are amongst the contextual factors considered for map adaptation.

On the completion of the project, a concluding assessment of the service that GiMoDig provides was done with technology users, comprised of private companies in the area of marketing regarded as the potential users of the service. For this aim six group meetings were held, discussing about different aspects of the system, the developed interfaces, context-aware map adaptation, dataset management, current state and perspectives of mobile technologies and applications with a very promising potential.

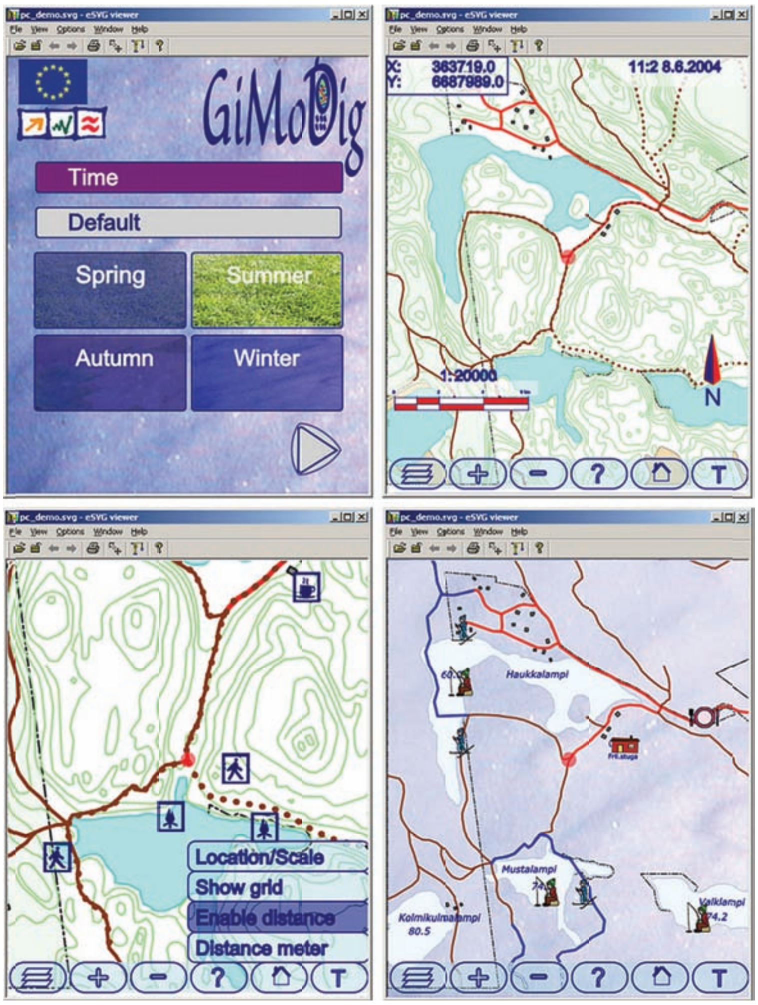


Figure 3.12: Context-aware map adaptation provided by the GiMoDig service prototype (adopted from: Sarjakoski & Sarjakoski, 2005).

3.4 Analysis

The research cases described in Section 3.3 reflect some of the past and recent research on mobile navigation systems for pedestrians. From these descriptions, several conclusions can be drawn. To start with, there is a clear focus on the development and evaluation of new technical solutions for the provision of location-based spatial information to prospective users. In six out of the seven presented cases, this is realized through the development of a prototype application, while in one (Case 4: Navitime), through the evaluation of an already widely used commercial mobile application.

Although all of the research examples are studies on the effects of applying different methods and techniques in order to reduce the complexity and to increase the comprehensibility of cartographic representations on mobile displays, research considering the user's mental interactions during mobile map use in real contexts is still short (Cases 1 and 3). This is an issue that other researchers (May et al., 2003), have earlier mentioned as well.

In Case 1 (m-Loma), landmarks are regarded as important features of the environment that help mobile users to orientate and navigate. 3D photorealistic maps are used to support the mental linking of the environment with the digital representation of it on the mobile display. Case 3 (EGSSystem) follows a different approach for the same aim, by using geo-tagged photos of real buildings accessible via icons on a mobile map, in order to support the personal geo-identification and orientation of the user through the linking between reality and the cartographic representation of reality.

There is also an indirect reference to the same issue in Case 4 (Navitime), where the orientation difficulty of a mobile user exiting a subway station is described, but without any details on the mental interactions that are involved. A 3D map representation, which is reported by the researchers (Arikawa et al., 2007) as more efficient in such situations (but without further explanation), is used here to support the user's orientation efforts. Another example of indirect reference to the user's mental linking between reality and the mobile maps is Case 5 (Lol@), where landmarks are used in order to induce better understanding of the route by the users.

It should be added here that there is no clear answer to the question of what is the best form to present landmarks to the users, although some efforts in this direction have been made. An example of this is the work of Elias et al. (2008)**. But the selection of particular landmarks based on the context and the user characteristics and preferences could highly affect the map usability. This is something that this research will investigate.**

Context awareness, altering map representation and content formulation through adaptation is directly mentioned in four Cases (2, 3, 4, 6 and 7) but involving different contextual parameters. In Case 2 (REAL), only the speed of the user is considered, affecting the map's scale, zooming speed, amount of detail (street and building names) and view perspective. An overview bird's-eye map is provided with high speeds and a detailed ego-centric map with low speeds. In Case 3 (EGSSystem), the visibility of the buildings, the location of the user and the use of past recommendations affect the amount and type of location-based information provided. In Case 4 (Navitime), the location of the user, the patterns of use, system capacities and cultural situations alter the map representation from 2D to 3D and vice versa, the interface arrangement and the language used. In Case 6 (MAPPER) the context-dependent user preferences change the layer- and feature- based data presented to the user. And finally, in Case 7 (GiMoDig), location of the user, age of the user, time of a day, season of the year and type of activity. Adaptation to multi-modal travelling situations is additionally described in Cases 2 (REAL) and 4 (Navitime).

With many different contextual parameters involved and different aspects of map presentation affected by them, it is apparent that there are no rules that can be followed for context awareness and different approaches can be applied. However, it could be argued that user preferences and profiles can be considered as the fundamental contextual parameters involved in any pedestrian navigation system as far as usability is concerned. This is the approach that will be followed in this research as well.

The problem of information overload in the limited-dimension mobile displays is regarded as important in more than half of the cases either related to context awareness effects (Case 4: Navitime and Case 7: GiMoDig), cluttering (Case 5: Lol@ and Case 7: GiMoDig) or the lack of preference-based map personalization (Case 6: MAPPER). In Case 5 (Lol@) only user limitations, such as visual impairment are taken into account as well. At the same time, speed and accuracy (Case 1: m-Loma and Case 7: GiMoDig), accuracy and convenience (Case 3: EGSSystem) and easiness and efficiency (Case 6: MAPPER and Case 7: GiMoDig) are expected from the mobile applications. In order to achieve this aim, considering besides other things the computational speed limitations of mobile devices, a server-client approach is mostly followed (Cases 1, 3, 4, 5, 6 and 7). Using wireless mobile connections such as Wi-Fi or GPRS / UMTS, an access to and exchange of information with multi-source, up-to-date and special-function databases is allowed. However, there are also data transmission speed and interruption issues which can again lower the performance of these systems. For that reason, solutions such as lightweight 3D techniques for transferring 3D building models (Case 1: m-Loma), use of the connection only for complex activities (Case 5: Lol@), and personalized vector map layer selection and transmission (Case 6: MAPPER and Case 7: GiMoDig) are proposed.

Although server-client configurations offer several advantages, such as possibilities for up-to-date information provision and reduced computation load to the mobile device, the current costs of mobile data connections and the data transfer problems encourage the use of off-line systems that rely on locally stored geodata and data processing capabilities. Considering the continuously upgraded technical characteristics of mobile devices, such as the size of program memory and the CPU speed, off-line systems can actually already handle much heavier graphic processing loads than in the past and efficiently deliver (carto-) graphic presentations of high quality to the user. In this research a combination of off-line and on-line approaches will be used, as this is regarded as adequate for the intended use.

Offering high levels of interactivity between the user and the application in the form of user-based content creation capabilities (Case 3: EGSSystem) interactive routing and searching (Case 4: Navitime and Case 5: Lol@) or interactive querying (Case 7: GiMoDig) is also a way to gain users' trust into the application and increase user satisfaction. In an effort to further support the achievement of these two goals, a creation of recommendations based on the inspection of the context of use and the acceptance of past recommendations is applied (Case 3: EGSSystem) or, alternatively, automatic user preference profiling, analysis and modelling for personalized task-specific content provision (Case 6: MAPPER and Case 7: GiMoDig).

In any case, high interactivity capabilities of the mobile applications increase their usability and thus promote their frequent use. However, the techniques and algorithms for doing that should be carefully selected, especially in the case of automated user modelling and provision of recommendations, as repeated faults of the system can induce negative responses from the user.

In most of the studied cases, there was a form of user test survey involved, aiming at the evaluation of particular technical approaches regarding rendering, information delivery, representation and content issues of maps for pedestrian mobile navigation systems. These evaluations were mainly executed during the last phase of the research projects, when usually all the ideas have already been formed into a functional prototype. However, at this point of time it are not the reasons behind certain development directions that are assessed, but the deliverables of them.

The exceptions to these usual practices are Cases 1 (m-Loma) and Case 7: GiMoDig). In Case 1, an initial user survey was carried out in order to provide an insight into the users' requirements and behaviour in real contexts of use. This was followed by a well-reported experiment for evaluating the implemented prototype. In Case 7 (GiMoDig), the user involvement in the design and evaluation of a prototype started right from the beginning of the project, during the requirement analysis stage. Following that, there was an iterative evaluation of successive prototypes with users, providing valuable feedback for further improvement of the designs and updating of the user requirements. These iterations lasted for the whole life span of the project, until a working prototype, which satisfied the usability goals set and the organizational requirements, was implemented.

The lack of published information regarding the execution of user surveys or, on the other hand, the provision of possibly invalid user research results, is also observed in half of the prototype evaluation cases. For example, in Case 3 (EGSSystem) although a general description of the user survey execution and the related results is given, the number of participants and the observation and analysis methodologies are not reported. In Case 4 (Navitime) an executed user research is encompassed in detail, but the involvement of only two participants does not allow for the production of valid results. A different example of the same issue is Case 5 (Lol@), where a user testing was planned but never executed. And finally, in Case 7 (GiMoDig), the aims and the results of a requirement analysis experiment are described but there is no information regarding the number of test persons and their demographics. Moreover, the testing methodology is not described in much detail. Apparently, in only one of the study cases (Case 7: GiMoDig) a user-centred design and implementation methodology, like UCD described in chapter 1 was used.

There is a clear need for more UCD-based approaches in the development of geo-mobile applications, as the usability of the current implementations remains a main issue. To design usable applications requires well-structured design and evaluation methodologies, such as UCD, which investigate and apply solutions based on the user needs, requirements and the context of use. In the research projects surveyed in this chapter the user is mostly not in the centre of the design and evaluation process but he or she is rather used as an outside tester of already completed products. This results in various usability problems which cannot be easily solved after the prototype development has been complete. However, this research will be UCD-based and thus well-

structured user surveys are planned to be executed both in the requirement analysis and prototype evaluation phases.

3.5 Conclusion

Going through the analysis of existing research on mobile navigation systems for pedestrians, this chapter outlined the framework inside which this research will evolve. The presented cases revealed valuable information regarding important parts that are still missing in current research but at the same time highlighted methodological and technical approaches that can be followed in order to develop more usable applications.

The key components were the landmarks, context-awareness, data provision methods, interactivity and user surveys as part of a UCD methodology. Based on these pillars and the theoretical ground of the 2nd chapter, it is now possible to answer the first two questions of this research.

The findings of the last two chapters have built the foundation based on which the conceptual design of a usable mobile cartographic interface that supports orientation and navigation could be realized. However, an experimental insight into the behaviour of real users and their interactions during spatial task execution in particular contexts of use would help to confirm these findings and also better specify the requirements for such applications. This is something with which the 4th Chapter will cope.

4. User-Centred Design and Requirement Analysis

The golden rule of design: Don't do to others what others have done to you. Remember the things you don't like in software interfaces you use. Then make sure you don't do the same things to users of interfaces you design and develop.

Tracy Leonard (1996)

4.1 Introduction

In the previous chapter a comparison between different geo-mobile applications for pedestrian navigation was made and the space for further research in this field was investigated. Going through different applications and inspecting the different design and development strategies followed, the selection of a convenient methodological approach for this research was shaped. The user would deserve a central position in that methodology, as it is not the technology alone that can produce usable solutions, but its use as a provider of efficient, effective and satisfactory information to the user. User-Centred Design (UCD) is an approach that meets this requirement, and it is increasingly applied for the development of usable geo-mobile applications as well as any other software application.

To better understand what the principles of UCD are, this chapter starts with an overview of research on usability during the last decades, looking through some of the different user-focused approaches available. UCD as a modern, well-structured methodology, appears to be a natural evolution in the usability research, and it is described in detail in terms of aims, strategies and expectations.

The UCD-based activities plan that fits the aims of this research is outlined afterwards, starting with the Requirement Analysis in which the profile of the user to whom this research is focusing on is created. In order to investigate the behaviour of such a user and his or her requirements while using a geo-mobile application, a field-based experiment was carried out and its results are presented here. The experiment also served as an essential element of the UWSM2 project (see Chapter 1).

4.2 Usability as an outcome of UCD

In this thesis, a term that frequently appears is "usability"; what is still missing is a detailed definition of what usability is, when it should be considered and how it is achieved. In literature, there has been a lot of discussion regarding usability, Human-Computer Interaction (HCI), UCD, Usability Engineering (UE), usability testing and related concepts. Often there appears to be a confusing interrelation between them. The International Organization for Standardization (ISO) provides us with a clear definition of usability: "Extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" (ISO 9241-11:1998, 1998). For Nielsen (1993) usability was a qualitative attribute for systems embodying learnability, efficiency, memorability, error recovery, and satisfaction of the user.

But who is actually a "user"? A clear definition that is adopted by this PhD was given by Gulliksen et al. (1999). For them, the term "user" points at a person who is using or going to make use of a particular product / system in order to accomplish tasks as parts of personal working or recreation activities. Additionally, coincidentally influenced persons, such as managers or technical assistants are acknowledged as "stakeholders".

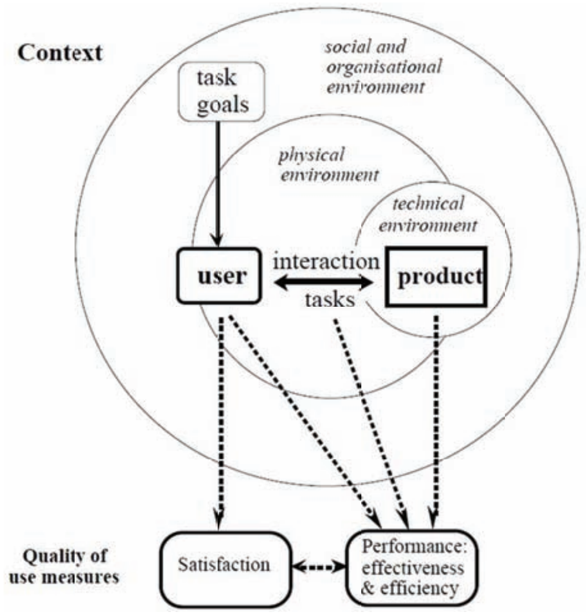


Figure 4.1: Context of use as a basis for determining measures of quality of use (or usability) (source: Bevan, 1995).

As indicated by Bevan (1995), usability is equivalent to quality of use, and in order to quantify that, it is particularly important to consider the nature of the user, his or her tasks and the environment where the product is used. In this regard, quality of use in terms of effectiveness, efficiency and user satisfaction is an outcome of a user-product (or system) interaction during task execution in three related environments (physical, social and organizational, constituting the "context of use". Context of use is thus a basis for determining measures of quality of use (or usability) (Figure 4.1).

The two roles of usability according to Bevan (1995) are first being an integral part of a product, and second, being the ultimate design goal of achieving quality at the highest level.

Usability is solely the result or a goal of a particular methodology, such as UCD, and not a methodology itself. However, it can refer to particular related fields of expertise such as UE or User eXperience (UX) (Spillers, 2008). In an earlier study on usability (Gould & Lewis, 1983) it is stated that when usability of a product is the goal, then its design should consider three phases. These are: early focus on users and tasks, empirical measurement and iterative design. This was further elaborated by Nielsen (1993) who divided the lifecycle of usability engineering (or in other words the process of designing for usability) into eleven stages (Figure 4.2).

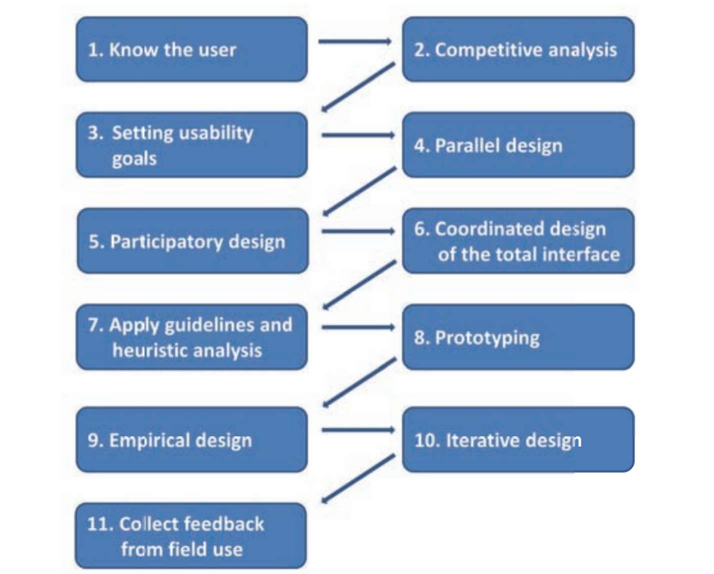


Figure 4.2: Lifecycle model of usability engineering consisting of 11 stages (based on Nielsen, 1993).

4.3 Human-Computer Interaction

The work of Gould & Lewis (1983) became the basis for the foundations of the Human-Computer Interaction (HCI) domain, which focuses on improving the interactions between humans and computing devices through user interfaces by making them more usable. HCI is often referred to as CHI (Computer-Human Interaction) as well. A definition states that: “Human-Computer Interaction is a discipline concerned with the design, evaluation and implementation of interactive computing systems for human use and with the study of major phenomena surrounding them” (SIGCHI Curriculum Development Group, 1992). HCI comprises a multi-disciplinary field embodying computer science, computer graphics, human factors, cognitive psychology, industrial engineering, (interaction) design and many other fields. Interactive computer graphics are of great importance in HCI. They are originating from the introduction of early computer CRT displays and pen-based input devices. That innovative (for the early sixties) technology led to the development of numerous HCI methods and techniques, mostly derived from the study of Sutherland (1963), which is regarded as the beginning of the field of computer graphics (SIGCHI Curriculum Development Group, 1992).

Usability is a fundamental principle in HCI and, as such, it initiated the development of different methodologies for the design, implementation and evaluation of usable user interfaces. Participatory or cooperative design was one of the first user-oriented methodologies that was adopted by HCI, involving the user in the design process from the very early stages onwards. Next to the users, the majority of stakeholders of a project are involved in a cooperative sense, such as the business partners, the researchers, the developers, and so on.

A milestone for cooperative design was the research done in the context of the project “Utopia” during 1981-1985 (Bødker et al., 1987). One of the main aims of that project was to improve the quality of support provided by computer systems to workers by involving end users in the systems’ design and development process. The “proof of concept” case for Utopia was the development of complete technical support tools for graphical professionals (Bødker et al., 2000).

The methodology applied involved three basic stages which are the common ground for most of the cooperative / participatory research done up to now. The first stage is initial exploration and problem determination based on ethnographic methods and techniques as for example interviews, observation, walkthroughs and inspections of objects in situ. The second stage is discovery of requirements through intense user-researcher interactions often in the form of group meetings. Role-playing games, storyboarding and future workshops are amongst the typical methods that are used in this stage. Finally, the third stage is iterative prototype development, which includes methods such as mock-up building, cooperative and paper prototyping and several other ones.

As part of the methodology, the end users are provided with the results of the whole process in an easily conceivable form, encouraging their continuous cooperation. Utopia contributed to the development of more modern methodologies such as contextual design (Bødker et al., 2000).

4.4 User-Centred Design fundamentals

UCD as a term was initially introduced by Norman & Draper (1986) and further elaborated by Norman (1988). His effort was on promoting UCD as a philosophy that builds on the user's needs and desires, concentrating on the creation of usable and meaningful products. The user is thus positioned at the centre of the design process while the designer should find ways to assist the user's tasks and to ensure that he or she can use the product for the purpose it is made for. Further, Norman stated that the time and effort needed for learning the correct ways of using the product should be the minimum possible and without the need for extensive and complicated manuals. According to (Norman, 1988, p. 188), a usable design should incorporate four main principles:

1. Make it easy to determine what actions are possible at any moment.
2. Make things visible, including the conceptual model of the system, the alternative actions, and the results of actions.
3. Make it easy to evaluate the current state of the system.
4. Follow natural mappings between intentions and the required actions; between actions and the resulting effect; and between the information that is visible and the interpretation of the system state.

Moreover, Norman (1988) proposed seven fundamental design rules that a designer should apply:

1. Use both knowledge in the world and knowledge in the head. By building conceptual models, write manuals that are easily understood and that are written before the design is implemented.
2. Simplify the structure of tasks. Make sure not to overload the short-term memory, or the long term memory of the user. On average the user is able to remember five things at a time. Make sure the task is consistent and provide mental aids for easy retrieval of information from long-term memory. Make sure the user has control over the task.
3. Make things visible: bridge the gulfs of execution and evaluation. The user should be able to figure out the use of an object by seeing the right buttons or devices for executing an operation.
4. Get the mappings right. One way to make things understandable is to use graphics.

5. Exploit the power of constraints, both natural and artificial, in order to give the user the feel that there is one thing to do.
6. Design for error. Plan for any possible error that can be made. This way the user will be allowed the option of recovery from any possible error made.
7. When all else fails, standardize. Create an international standard if something cannot be designed without arbitrary mappings.

The work of Norman evolved further into alternative but at the same time related sets of rules for UCD-based usable interface design proposed by different researchers such as Shneiderman (1987) and Nielsen (2001). However, a standardized description of UCD only became available with the release of ISO 13407, entitled "Human-centred design processes for interactive systems" (ISO 13407:1999, 1999). That standard provides directions for accomplishing usability through UCD strategies and actions from the beginning to the end of life of interactive systems based on computers. ISO 13407 focuses on an iterative cycle of development where the user and organizational requirements and characteristics but also the contexts of use of the product/system are accurately regarded. The outcome of that development is the production of design solutions which are then evaluated upon the initially set requirements. According to ISO 13407, five stages should be performed from the beginning of every UCD project:

1. Plan the human centred process.
2. Understand and specify the context of use.
3. Specify the user and organizational requirements.
4. Produce design solutions.
5. Evaluate designs against requirements.

These stages, four of which are inside an iterative loop are illustrated in Figure 4.3.

UCD is increasingly applied to mobile interfaces and in geo-mobile applications as well (see e.g. Haklay & Nivala, 2010). However, the findings of Chapter 3 are that there are still a large amount of solution-centred design approaches in current projects coping with geo-mobile applications. In those approaches, the user does not hold a central part in the design process but rather a limited role as just the evaluator of already developed solutions. Therefore, the role of UCD as a valuable tool for producing usable interfaces for geo-mobile applications will be tested in this research as well.

At the start of UCD, the requirements of the design in terms of contexts of use and user, and organizational (or business) demands have to be specified. This can be done in the context of a global requirement analysis stage, incorporating phases 2 and 3 of the ISO 13407 standard (see Figure 4.3). This idea was clearly presented in van Elzakker & Wealands (2007). The outcomes of the requirement analysis provide the guidelines for producing design solutions first at a conceptual level and then in the form of prototypes. These prototypes can then be iteratively evaluated, providing instructions for further improvements until the design meets the requirements initially identified. An illustration of this refined process is shown in Figure 4.4.

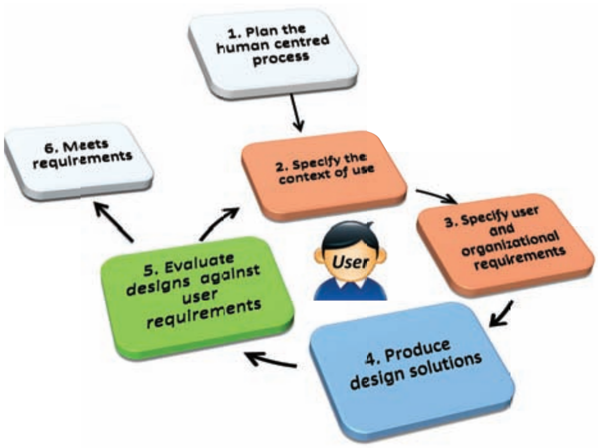


Figure 4.3: The five stages of UCD, their interrelations and the involved activities for each stage (illustration based on ISO 13407:1999, 1999).

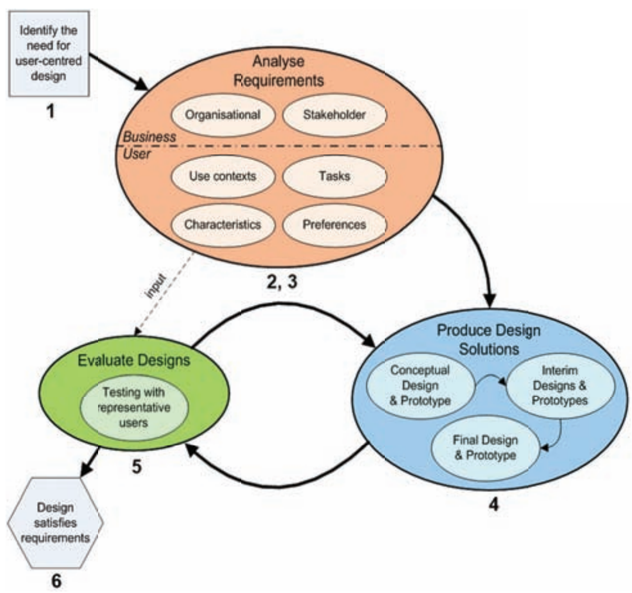


Figure 4.4: The design process in UCD (adopted from: van Elzakker & Wealands, 2007). The numbers 1 to 6 refer to the stages of UCD shown in Figure 4.3.

4.5 Specific research methods and techniques in the three stages of the UCD process

Although ISO 13407 provides general guidelines for designing and planning UCD activities, the selection of research methods and techniques required to complete each stage of UCD is not described in detail (Jokela et al., 2003). Considering this limitation, Wealands (2007) did a survey of different existing usability research methods and techniques, qualitative and quantitative, which could be used in the different stages of UCD. However, in her selection some of the commonly used methods and techniques were missing and other ones were limited to only one particular stage of UCD while they may actually be applicable to many. Therefore, an extended and amended collection of methods and techniques for UCD, divided into 3 main categories based on the framework of Figure 4.4 is presented in Table 4.1.

Analyse Requirements	Produce Design Solutions	Evaluate Designs
Survey / interview of existing users	Usability goal setting	Usability Inspections
User requirements interviews	Design guidelines and standards	Usability testing in the lab
User profiling		
Contextual Observations / interviews	Scenario-based design	Usability testing in the field
Diary keeping	Parallel design	Post-experience interviews
Task analysis	(paper- or working interface-) Prototyping	Heuristic evaluation
Competitive analysis	Card sorting	Focus groups
Card sorting	Focus groups	Satisfaction questionnaires
Personas	Individual interviews	Expert reviews
Scenarios of use	Surveys (online)	Surveys (online)
User / task models	Usability testing	Diagnostic evaluation
Interaction modelling		
Heuristic evaluation	Use cases	Performance testing
Usability testing	Style guide	Critical incidence technique
Evaluating existing system(s)	Wizard of Oz	Remote evaluation
Brainstorming	Heuristic evaluation	Logging
Affinity diagramming	Interface design patterns	
Requirements meeting	Rapid prototyping	

Table 4.1: Methods and techniques of use and user research that can be used in UCD (adapted from Mayhew, 1999; Nielsen, 1993; Vredenburg et al., 2002; Wealands, 2007; URL29).

The specific methods and techniques that are selected for this research, as well as the justification for their selection, are described into more detail below and in the chapters that follow.

4.6 UCD methodology for geo-mobile interfaces as applied in this research

The overall aim of this research, as presented in Chapter 1, is the design and evaluation of a cartographic interface for geo-mobile applications that facilitates personal geo-identification and supports spatial activities in the context of a pedestrian user in unfamiliar environments. Designing such an interface with usability in mind suggests that a carefully defined UCD-based strategy should be constructed. Starting with the requirement analysis, the profile of a user, his or her needs, characteristics and tasks are established. Traditional methods used for requirement analysis, such as interviewing existing users or brainstorming, many times fail to consider (in depth) the impact of context. Therefore, a field-based experiment where visitors to unfamiliar areas would be given a series of tasks of orientation and navigation with the use of existing geo-mobile applications would provide a more sound approach.

The outcomes of such an experiment may be converted into a series of tasks involving the use of a mobile navigation system as a supportive tool. From a task analysis the information requirements for orientation and navigation task execution can be derived, forming the basis for use case modelling. Then the system design requirements can be set and reflected into a model of user-system interactions. In that model, the system responses to user's questions related to each orientation / navigation task can be established. Using the UML language, the use-case modelling and the user-system interaction model can be converted into software code that helps building a prototype interface. Finally, usability testing in the field can be executed in order to evaluate the prototype in a real context of use and users. This provides the feedback for improvements of the prototype. The last stage can be repeated a few times until the requirements are met but it can also lead to a usable prototype which needs minor modifications based on the users' performance. A schematic representation of the UCD-based scheme of this research, encompassing methods included in Table 4.1, is shown in Figure 4.5. Following this scheme, the remainder of Chapter 4 copes with the first part of the Requirement Analysis stage, including user profiling (Section 4.7) and experimental investigation of user requirements (Section 4.8). The second part of the Requirement Analysis stage is presented in Chapter 5, including User Task Analysis (Section 5.2), Outlining Information Requirements (Section 5.3), Use Case Modelling (Section 5.4), and Outlining System Design requirements and

Interaction Modelling (Section 5.5). After the Requirements Analysis stage is completed, the Producing Design Solutions stage is carried out and described in Section 5.10. Finally, Evaluation of Designs is performed and presented in Chapter 6.

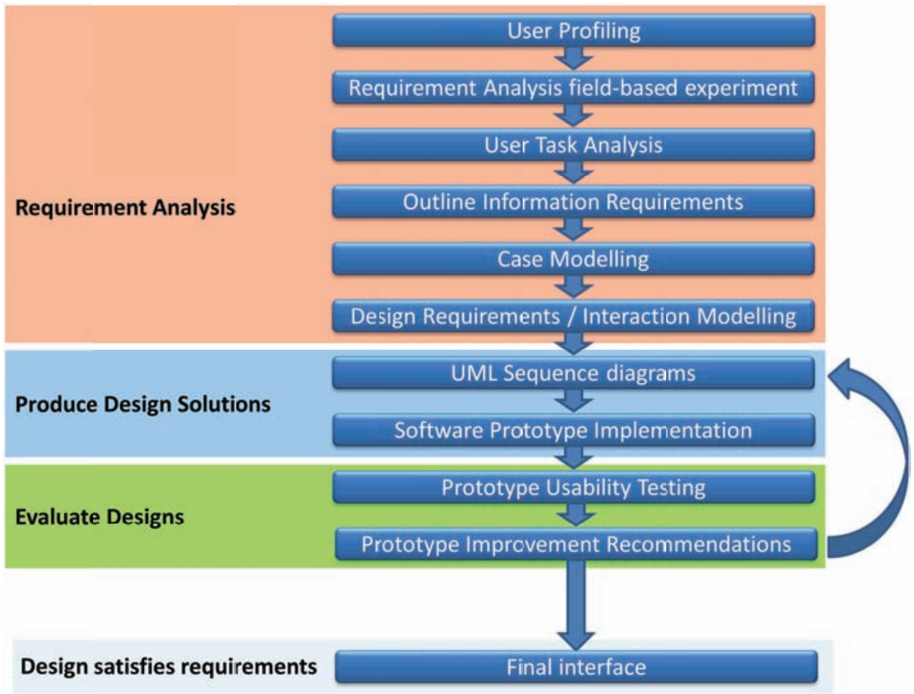


Figure 4.5: The UCD-based scheme of the research.

4.7 User profile

User profiling is the first activity of the requirement analysis stage, and constitutes a description of the basic characteristics of the persons who are going to use the mobile interface. The general profile of the potential user group of interest in this research has already been given in Chapter 1. In more detail, the characteristics of this user group are provided in Table 4.2.

A starting point like this is required in order to limit this research, making the experimental investigation of the needs, requirements and problems of this type of users feasible. The design, methodology and results of such an experiment are presented in the next sections of this chapter.

Age	18 to 60 years old
Ethnicity	Dutch or foreigner
Gender	Male or female
Education level	Any
Activity of interest	Travelling to unfamiliar cities
Purpose of trip	Tourism or business
Time available for travelling	Limited (no sightseeing possible) or plenty (sightseeing possible)
Technological abilities	-Able to (learn/understand how to) use a mobile device with touch screen -Able to (learn/understand how to) use a mobile navigation application

Table 4.2: Characteristics of the potential user group.

4.8 Experimental investigation of user requirements

In order to further define the design goals and determine the user needs, a field-based user experiment was executed. The experiment was built upon the following basic scenario: Imagine a person visiting an unfamiliar city and leaving an underground railway station through one of many exits. Such a visitor may not immediately know where he or she exactly is. But the understanding of "where am I?" is a necessary first step before finding solutions to follow-up spatial problems such as in which direction he or she should move in order to reach a particular destination.

Several types of landmarks and other structural elements may act as common points between the virtual and real worlds available to mobile map users, as described in Sections 2.5.1 and 2.5.2. One of the aspects to be investigated in this research was what are the landmarks that users of mobile geo-applications, and in particular visitors to unfamiliar cities, use in order to orient themselves, navigate and perform wayfinding (research question I). When generalizing map displays, for instance, such landmarks may then be kept visible in every scale, so as to foster the relationship between the real world, the mobile map and the mental maps of the mobile users, to help answering their possible geographic questions, even when they are "toggling" between obtaining overview and important spatial details.

From the research objectives and the study of related work presented in Chapters 1, 2 and 3, the following questions that guided the set-up of the experiment were derived:

- What is the type of information users of geo-mobile applications are first seeking for in order to geo-identify themselves when they enter an unfamiliar area in a city for the first time?

- What are the landmarks existing in both the users' mental maps and in mobile maps that are important for personal geo-identification and navigation / wayfinding?
- Do users have problems with linking landmarks, as they appear in reality, with those appearing on the map display?
- Are the 'mental' landmarks of users properly linked to the map displays generated by the geo-mobile applications?
- In which ways do users use landmarks when they try to orient themselves?
- How often and when are users confused about their location and what is the reason for that?
- When users know where they are, do they still make mistakes in deciding which direction to take in order to navigate to a destination? If so, what are the reasons for that?
- Do users benefit from the use of smooth zooming techniques in mobile maps rather than step-wise zooming?
- Do users benefit from 3D map and landmark representations?

In answering these questions it was not the intention to obtain statistically valid quantitative results, nor was it the intention to evaluate the already existing geo-mobile applications that were used in the requirement analysis experiment. The objective of the field-based experiment was to provide information about user requirements for personal geo-identification and pedestrian navigation that may be used for future prototype design. For our experiment, two existing geo-mobile applications with different characteristics were selected in order to be used by a group of test persons (TPs) to perform real world tasks, related to personal orientation and navigation in the context of a visitor to an unfamiliar city. The TPs were observed and their thoughts, behaviour and performance were recorded and analysed.

4.8.1 Selection of geo-mobile applications

Although today there are many different geo-mobile applications available on the market (Table 4.3), most of them are navigation applications for vehicles with only minor abilities for pedestrian navigation (see Section 1.1 and 2.2.5). Table 4.3 contains the same applications as Table 3.2. The applications investigated are Windows Mobile v.6 compatible, because of the equipment that was used in the requirement analysis experiment.

The selection of two applications for the experiment was made on the basis of the following criteria:

1. Landmarks presented in 3D
2. Coverage of the study area (Amsterdam)
3. Zooming / panning functions
4. Smooth zooming capability
5. Availability to the researchers.

Release year	Web link	Application	1. 3D landmarks	2. Amsterdam coverage	3. Zooming / panning	4. Smooth zooming	5. Availability
2008	URL1	agis Navigator v.2.0	N	N	Y	N	N
2006	URL2	Alturion GPS Professional v.6.0	N	Y	Y	N	Y
2009	URL3	amAze v.4.2	N	Y	Y	N	Y
2007	URL4	Co-Pilot Live v.7.0	N	Y	Y	N	Y
2007	URL5	Destinator 7	N	Y	Y	N	Y
2007	URL6	Google (mobile) Maps	N	Y	Y	N	Y
2007	URL7	Google Navigator v.3.6	N	Y	Y	N	Y
2006	URL8	iGo My way 2006 plus	N	Y	Y	N	Y
2008	URL9	iGo My way v.8.0	Y	Y	Y	Y	Y
2008	URL10	INAV i-Guidance v.4.0	N	N	Y	N	Y
2007	URL11	Intellinav v.2.0	N	N	Y	N	N
2006	URL12	Maptech Memory Map v.5.0	N	Y	Y	N	N
2006	URL13	Marco Polo Mobile Navigator 3	N	Y	Y	N	Y
2006	URL14	MioMap v.3.0	N	Y	Y	N	Y
2007	URL15	MioMap 2008	Y	Y	Y	Y	N
2009	URL16	Navigon Mobile Navigator v.6.0	N	Y	Y	N	Y
2007	URL17	Nokia Maps (Smart2Go)	N	Y	Y	N	Y
2006	URL18	Odyssey Mobile 4	N	N	Y	N	N
2008	URL19	OnCourse Navigator v.6.0 Plus	N	Y	Y	Y	N
2005	URL20	Pharos Ostia	N	Y	Y	N	N
2005	URL21	PocketMap Navigator (USA)	N	N	Y	N	N
2007	URL22	PocketWAW v.3.0	N	N	Y	N	Y
2006	URL23	Route 66 Navigate 7 PPC	N	Y	Y	N	Y
2006	URL24	Teletype GPS	N	Y	Y	N	N
2006	URL25	Tom Tom Navigator 6	N	N	Y	N	Y
2006	URL26	Via Michelin	N	Y	Y	N	N

Table 4.3: Examples of existing (Windows Mobile 6.0 compatible) geo-mobile applications (numbers refer to the criteria explained in the text).

The application that met all the criteria was iGo My way v.8.0 (Figure 4.6a). Google (mobile) Maps (Figure 4.6b) was selected for comparison reasons: it did not offer smooth / animated zooming functionalities and no landmarks on the map display, but it was expected that this application would gain a wide distribution in the near future. Considering that the experiment was executed on May / June 2008, that prediction was correct. Google Maps is currently one of the most widely used mobile applications of any kind, with 100 million users worldwide (URL34).

a b

Figure 4.6: The test applications used in the experiment: iGo My way v.8.0 (a) and Google Maps (b) showing the same region of Amsterdam in 3D and 2D respectively.

4.8.2 Test persons

The experiment had to be executed with a specific type of user representing a visitor to an unfamiliar city using a geo-mobile application (see Table 4.2 with the user profile). This visitor is "dropped" at a location unknown to him or her and is supported by the information provided by the mobile interface. Suitable TPs would not have to be deterred by using a mobile application and the selected age range was from 18 to 60 years old. They could have different levels of knowledge in terms of (mobile) maps, use of mobile devices, cartography and orientation and navigation techniques and abilities.

The 8 TPs that took part in this experiment were recruited from MSc and PhD students of the ITC (the International Institute for Geo-Information Science and Earth Observation). It is true that, compared to ordinary tourists, they may have a more than average affinity with maps and geo-mobile applications, but they do not originate from the Netherlands and were not familiar with the study area. They felt attracted to Amsterdam and free transport to this city was the stimulus for them to participate in the experiment.

Five male and three female TPs participated in the experiments, with their age ranging from 24 to 47 years old. They had different countries of origin. The profiles of the TPs are shown in Table 4.4 and their background in fields related to this research in Table 4.5.

Nr.	Age	Gender	Origin	Profession
TP1	34	M	India	Civil Engineering
TP2	27	F	Indonesia	Traffic Management-Transport Behaviour
TP3	38	M	Iran	Ecological Modelling-Marine Engineering
TP4	47	M	Iran	Hydrology & Water Resources
TP5	25	M	China	Geographic Information Science
TP6	24	F	China	Geographic Information Science
TP7	29	M	Pakistan	GIS Software Engineering
TP8	26	F	Pakistan	Geo-hazards Management

Table 4.4: General profiles of the TPs.

Nr.	GPS systems	Digital maps	PDA	Mobile navigation apps
TP1	Modest	Very good	Very good	Very good
TP2	Poor	Modest	Modest	Modest
TP3	Modest	Modest	Modest	Poor
TP4	Poor	No	No	No
TP5	Modest	Very good	No	No
TP6	Poor	Very good	No	No
TP7	Modest	Modest	Modest	Poor
TP8	Modest	No	No	Poor

Table 4.5: Experience of the TPs in fields related to the research.

Most of the TPs had already visited Amsterdam in the past, but no one had been to the test areas and they were thus unfamiliar with them. Besides, no one had previous experience with any of the two geo-mobile applications used in the experiment.

A questionnaire was applied (see Appendix 1) to find out more about the ways in which the TPs normally use and combine different sources of information when they try to orient themselves and navigate in space:

Most of the participants always or frequently prepare themselves before they go to an unfamiliar city or area and the others sometimes do that. The main sources of information for them are city maps, either printed on paper or consulted on a computer screen. Finding on the map the public transportation stations and the routes to their places of stay, together with points of interest and prominent buildings, are their most important goals. One of the participants also mentioned the need to see pictures of the points of interest in the city so that they can be recognized easily later on. Asking other people that have already visited the place is also important for half of the participants, in order to learn about important points of interest that they should visit or can use as landmarks for orientation and navigation purposes.

All TPs sometimes or frequently take the responsibility of orientation and navigation, and the use of paper maps is a common task for them. However, this does not imply that they always complete these tasks with ease, as all of them have sometimes or even always (TP6, TP8) difficulties to orient themselves in unfamiliar areas with the use of paper maps.

Only one TP (TP2) makes frequent use of a mobile navigation system when travelling to an unfamiliar place, while the others never do that. This is an interesting outcome of the questionnaire, as more than half of the participants had answered earlier that they have some experience with mobile navigators.

After their arrival in an unfamiliar city, more than half of the TPs inspect the layout of the city, and the patterns of the streets, in order to try to understand the city better and not to get lost. Besides, half of them are trying to find and locate some easily distinguishable landmarks: churches or other tall buildings (3), train / bus stations (2), big shops, restaurants (1) and rivers (1). When they do get lost, half of them are trying to find their way through street name information, compared to a map, or to find a previously memorized landmark such as a church, a transportation terminal or a big building. Less than half of the TPs would also ask local people to explain to them where they exactly are and to point their position on a map that they may carry. One of the participants (TP1) also uses the sun direction and tries to re-orient the map towards the North.

All TPs find their orientation and navigation abilities improved when they are visiting the city for a second time. According to them, the reason is the memorization of transport stations (2), tall structures, buildings and city centres (3), patterns of the cities (1), previous routes (1), appearance of roads (1) and any other easily distinguishable / unique features (1).

4.8.3 Study area

Amsterdam was the selected city for the experiment for three reasons. First, it is visited by many people (e.g. tourists) who have not been there before and they often go there by public transport. Secondly, Amsterdam (Department of "Stadstoezicht") took part in the UWSM2 project (see Section 1.1) as well, as the municipality would like to use a geo-mobile application in relation with parking services. And, thirdly, the train trip from Enschede (the temporary dwelling-place of almost all TPs) allowed for interaction between the researcher and the TPs in order to prepare the latter for the experiment and acquire some important additional research data.

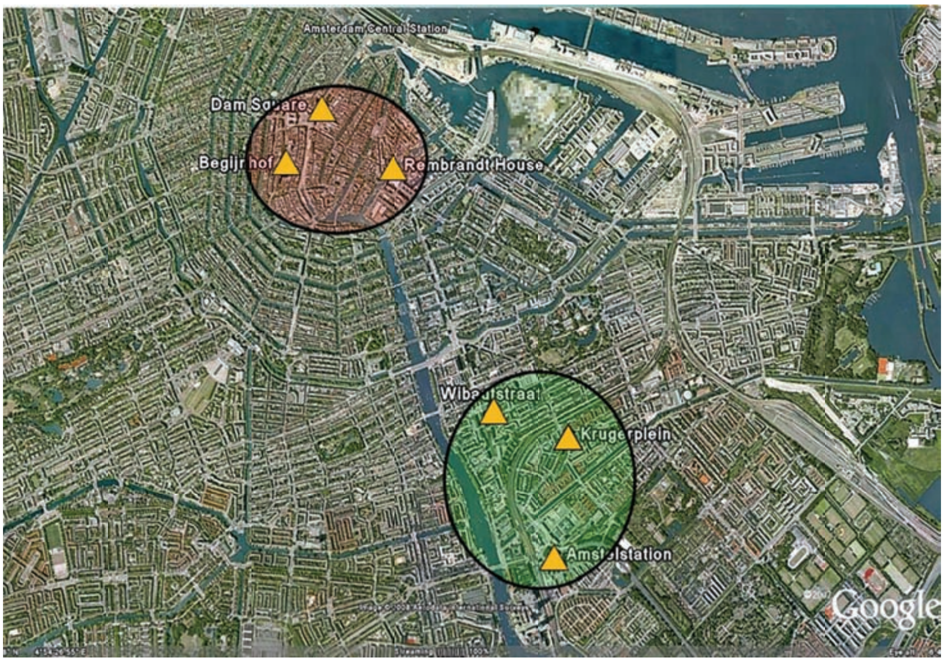


Figure 4.7: The test areas Wibautstraat-Krugerplein-Amstelstation (in green colour) and Dam Square-Begijnhof-Rembrandt House (in pink colour) placed in Google Earth.

For executing the tests, two different areas of Amsterdam with different environmental parameters were selected, in order to investigate how this diversity influences the personal geo-identification and navigation of the TPs. The first (based on the test route) was Wibautstraat Metro station (start) – Krugerplein (1st destination) – Amstel Metro Station (2nd destination) and the second was Dam Square (start) – Begijnhof (1st destination) – Rembrandt House (2nd destination). These can be seen in Figure 4.7. The first area has less diversity of features (neighbourhoods mostly comprised of houses) and the second includes many prominent places that could be used as landmarks (churches, governmental buildings, historical places).

4.8.4 Research methods and techniques

The testing methodology involved a questionnaire at the start, thinking aloud with audio/visual observation and synchronous screen logging and a semi-structured interview at the end. The standard questions of this interview are shown Appendix 3. This combination of methods allows for a deep investigation of the TP's thoughts and actions, and keeps, at the same time, records of all the test activities. The resulting research materials may be thoroughly and objectively analysed afterwards (Delikostidis, 2007; van Elzakker et al., 2008).

The questionnaire had the aim of creating a general profile of the TPs, involving their experience, knowledge and way of acting in fields related to this experiment. Thinking aloud proved to be a very valuable technique for acquiring information about the TP's thoughts and the reasoning behind their acts, especially in parts where they were confused. During the interview at the end the TPs could also discuss additional issues and could also be asked several questions depending on their previous answers. This was especially useful for clearing things out when there was a noticeable difference between answers of particular TPs in the initial questionnaire and their behaviour and acts during the survey.

The TPs were also asked to draw two mental maps, depicting their place of residence and the route that they followed during the testing. The first mental map was drawn after completing the questionnaire and the second one after finishing the interview. In these drawings they were supposed to include the geographical objects they found important both for a familiar area (their place of residence) and an unfamiliar one (the test area). From the mental map drawings a lot of information can be retrieved, such as the type of landmarks memorized, the points of confusion and the possible reasons for that and the individual's orientation abilities.

The 8 TPs were divided in two groups of 4 people each, one group for each of the two study areas in Amsterdam. The TPs in both groups were asked to use the two selected geo-mobile applications one after the other, performing one navigation task with each application. Each test started by asking the TP to try to orient with the help of the first geo-mobile application without using street names and then select and follow the shortest route to navigate towards the first destination. After reaching that point, the second application was used in order to execute the same tasks targeting to the second destination. The order of applications was changed every time for comparison reasons.

Although the real contexts of use are dynamic and even unpredictable up to some extent, a set of conditions was applied to the test sessions in order to limit the context diversity as much as possible. The test sessions were only executed during daytime (from 8:00 to 20:00 hrs. in the months May and June 2008), in fair weather conditions (cloudy or sunny days, with average temperature and wind speed) and not in highly disturbing instances (demonstrations, national celebrations, road work and the like) in the survey areas.

Before the actual involvement of the TPs, a pilot study took place in the selected areas in order to calculate the required average times for the completion of each task, to test the equipment in real conditions and find out possible problems or limitations that could affect the execution of the tests. After the pilot study, some adjustments to the survey settings had to be made. The initially estimated timings of the different parts of the test were revised and some of the equipment was calibrated in order to work properly with respect to the field's specific parameters (high environmental and electromagnetic noise, possibility of short-time light rain, low GPS signal in narrow streets).

4.8.5 Briefing and training of the test persons

During the transportation of the TPs from Enschede to the test areas by train (two TPs per day) the TPs were first asked to complete the questionnaire and then draw the mental map of their place of residence. Then they were given the mobile device (a PDA HP iPAQ 4700hx and later a PDA-smartphone i-mate Ultimate 9502) running iGo My way v.8.0 and Google Maps, with the latter running offline using Google Navigator software (URL7). The GPS receiver of the mobile device was on while the train was moving, so that the TPs could better understand how each mobile application was working, how they could use the basic functions (zooming, panning) and how the viewing perspective could be changed from 2D to 3D and vice versa. Two city- and street-name finding tasks involving zooming and panning were also given to the TPs, in order to make them more familiar with the functionalities and interface of the geo-mobile applications. The TPs were informed that the test would start as soon as they had reached the Wibautstraat Metro station (for TPs in the first group), and Dam Square for those in the second group. Additional instructions regarding the execution of the tests and information regarding personal and equipment safety were given as well. The literal instructions given in the briefing session are provided in Appendix 2.

4.8.6 Mobile observation and thinking aloud in the field

In order to carry out the experiment, a special technical solution for field-based observation/recording was used. It is based on a system that was also built by the author and already implemented during an earlier investigation on methodologies for field-based usability evaluation of geo-mobile applications (Delikostidis, 2007; van Elzakker et al., 2008). This system consisted of several electronic devices, such as two pairs of audio transceivers, three B&W cameras, a laptop, a handheld video recorder, two pairs of video transceivers and a video quad processor. This complicated system was needed in order to reduce the bias from the researcher physically being too close to the TPs, to minimize the human resources required for carrying out the test sessions and to facilitate the analysis of the recorded research materials through synchronization. With this system, the thinking aloud audio signal, the camera observations of the user, the environment and his or her interaction with the mobile device and the logging of the changes on the screen were synchronically recorded with a date / time stamp. The context of use and the participants' activities and expressed thoughts could thus be analysed later with accuracy, speed and convenience.

For this experiment, the original system was improved and upgraded in order to offer higher reliability, simplicity and performance. Its main parts are a pair of DECT phones connected to headsets, a hard disk-based four-channel mobile video / audio recorder, three high resolution and wide view colour cameras, two pairs of video transceivers, a TFT colour video monitor and a mobile device, an i-mate Ultimate 9502 with integrated GPS receiver and video-out capability, running Windows Mobile 6.0 (Figure 4.8). The DECT phones were used as wireless intercoms offering good quality and uninterrupted audio communication between the researcher and the TPs during the sessions. The pair of headsets that both of them were wearing was connected to the DECT phones, through which the thinking aloud could be performed and through which researcher and TP could interact.

The TP wore a hat with two of the colour cameras attached on it. The first one captured his or her interaction with the mobile device and the second one his or her actual viewpoint. A third camera was carried by the observer, capturing the interaction of the TPs with the environment from a fair distance (20 to 100 meters) and sending this image wirelessly to the user's video receiver. In addition to these inputs, a real-time screen capture of the mobile device display was provided through its integrated composite-type video output.

All the four video signals together with the audio communication were recorded in the 4-channel mobile video / audio recorder, which has enough storage space for many hours of continuous recording. The advantage of using a 4-channel system rather than a single channel one is the higher quality of video per channel, while at the same time there is synchronization between the video / audio channels and date / time stamping which has the benefits described earlier. The researcher could observe all the recorded video signals wirelessly and simultaneously in a quad view (four images in one screen) on the colour monitor that he carried, through a pair of video transmitters / receivers connected to the mobile recorder and the monitor respectively (Figure 4.9).

This configuration also overcomes the issue of battery power shortages that came to light in the earlier testing. It allows the continuous use of the system for many hours by simply charging a pair of lithium-ion battery clusters for powering the several devices beforehand.

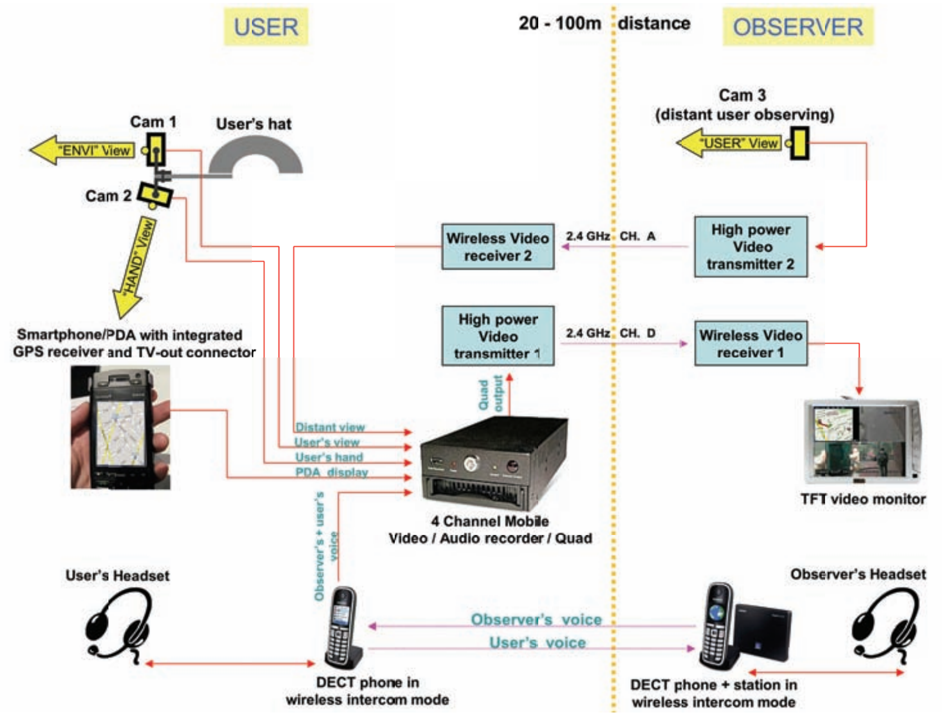


Figure 4.8: Schematic diagram of the field observation / recording system.

Figure 4.9: Sample screenshot of the video recordings of the system.

When the researcher / observer and the TPs reached the starting-point, a preparation and installation of the devices of the field observation and recording system was taking place for about 5 to 10 minutes. After that, a few final instructions were given to the TPs and they were able to start the test (Figure 4.10).

Figure 4.10: Equipment checking and final instructions to the TP just before the start of a test session at the Dam Square.

Figure 4.11: One of the TPs thinking aloud while trying to orient themselves in front of Begijnhof entrance. The researcher is observing the participant's interactions through the video monitor.

During the test sessions, the participants had to speak aloud about their thoughts, decisions and confusions. The researcher was frequently reminding them to think aloud every time they forgot to do so, asking them questions and encouraging them to try finding alternative ways to solve their problems. In order to be able to derive useful conclusions about the interaction between mental maps, reality and mobile maps, the TPs were frequently asked to describe what are the landmarks, features, patterns or any other type of information that they used to orient themselves and navigate in each situation. It was considered important to inspect what the TPs were looking at during the task execution, even though they were sometimes doing that unconsciously. Questions to the users triggered by these instances provided very interesting and valuable answers. These answers helped in formulating hypotheses about the connections between the real and virtual worlds and in better understanding the process of geo-identification (Figure 4.11).

4.9 Results and analysis of the requirement analysis experiment

4.9.1 Task execution

The test sessions took place between 24 May and 14 June 2008. In general, there were no major problems with respect to the research methodology. There were only a few minor random technical problems with the electronic devices used, which could be expected in this type of research.

The TPs were encouraged to think aloud during the test sessions while trying to orient themselves and navigate with the use of a geo-mobile application. However, thinking aloud was not always easy for them. In several cases the TPs stopped walking and were trying to say what they thought. Outside this apparent verbalization problem, the think aloud method led to valuable results, especially in instances where the TPs were confused about, for example, the selection of a path or direction of movement.

Disturbance by residents or tourists asking about what exactly was the subject of this research was one of the issues that it was expected to be confronted with. Although that happened a few times during the test sessions, it did not influence their proper execution. Providing a fast and polite explanation was an effective solution that worked in every instance.

4.9.2 Mental maps

The mental map drawings of Enschede (the town of residence for most of the participants) and those of the test areas in Amsterdam, give an overview of what landmarks the TPs find important to be stored in their minds. They also demonstrate differences from person to person in terms of perception of space and easiness of building mental maps of new areas.

Figure 4.12 shows the mental maps of one test area of two different TPs: TP2 and TP5. The park near destination point 2 and the canal are included in both drawings. The main roads are also very important for both of them, and TP2 even remembers the name of one road. Although during the actual testing both of these TPs found the rail track very important to orient themselves, it was only included in TP2's mental map. TP5, on the other hand, included a big roundabout existing near destination point 3. This roundabout was a point of confusion for that participant during the testing, as it was difficult for him to select which of the surrounding streets was the correct one to follow.

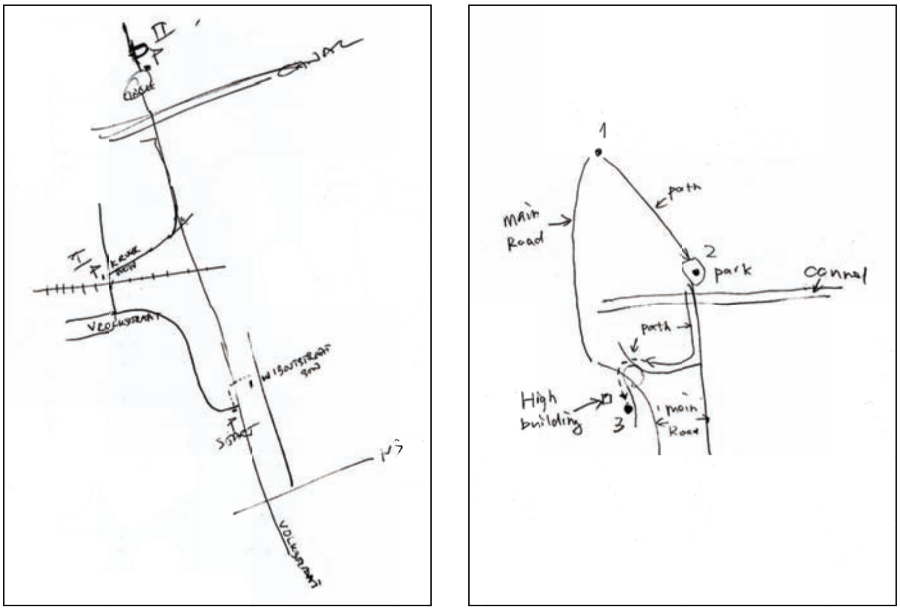


Figure 4.12: The test area Wibautstraat-Krugerplein-Amstelstation as perceived and represented by TP2 (left) and TP5 (right) respectively.

Landmarks and features that most of the participants included in their mental map drawings were main roads, places of residence and work, transport stations, railroads, tall buildings, squares and parks, big shops / supermarkets, city centres and canals / rivers. However, a major complaint of the TPs was that they could actually not collect as much information of the environment as they would if they would not use the geo-mobile application continuously. For example, two participants mentioned that they would memorize the location and appearance of shops or they would have noticed several tall buildings along their route if they were using a paper map or no map at all. Apparently, they found it difficult to focus on the mobile map and real world at the same time.

4.9.3 Test outcomes

The results of the semi-structured interviews, combined with the answers to the questionnaires, the think aloud protocols and video recordings of the observations and screen logging during the actual tests and the mental map drawings were used to answer the research questions as listed in Section 4.5. Only a selection of outcomes will be presented here:

The first information that TPs as visitors to an unfamiliar city searched for in order to geo-identify themselves was their position on the map display through the GPS location arrow. They then linked this to the patterns and sizes of the streets on the map and compared them to those in reality, as seeking for street names was not allowed at the starting points. It became clear that for personal geo-identification and navigation with the help of geo-mobile applications, the TPs preferred simple map displays with clear colouring and road sizing related to the actual size of the roads in reality. In this respect they preferred Google (mobile) Maps, complaining, however, about the fact that many important landmarks were not shown on the map of this application.

The types of landmarks and features that helped the TPs to orient themselves and navigate during the tests were the canals, the road patterns and sizes, the street names and the parks / squares and roundabouts. Landmarks that would help them but were not (always) available on the map displays are the bridges, pedestrian paths crossing roads, important buildings, such as municipal offices, or tall buildings that are visible from a distance. Specific landmarks that they expect to come across in order to help them to find their way in an unfamiliar city are big shops and easily distinguishable restaurants, such as fast food branches, churches, noticeable monuments, canals, bridges and parks. Besides, it appeared that the types of landmarks in both the users' mental maps and the mobile maps to support their geo-identification and navigation / wayfinding partly depend on the type of the area. For example, canals and bridges were perceived as very useful landmarks in Amsterdam. Or, in an area with not so many prominent features, a small park or a roundabout gain more importance than they would in an area with many easily distinguishable buildings. The TPs had difficulties in distinguishing the landmarks on the map displays and were looking for additional information in order to identify and verify them.

Applying advanced solutions to the issue of landmark visualization is not always producing better results. Indeed, as it comes to 3D representation and 3D building models on mobile maps, most of the TPs indicated that it is confusing to have a plethora of 3D buildings on the map and they would prefer to only see important 3D landmarks (which would make the software running faster and smoother as well). One of the participants complained about the perspective view of the 3D maps which is not a human-eye view but a bird's-eye one, making it difficult to interpret the image of the map correctly inside the human mind. Indeed, most users preferred to use the 2D rather than the 3D map display in this research. However, in this respect no general conclusions can be drawn, as the TPs could not really get used to the different visualizations in the relatively short time of the experiment. The 3D map interface had more functions than the 2D one and many persons confessed that they were afraid to use it as they were getting confused with the totally different way of visualization. They confirmed that the 3D models of the buildings could improve their mental connection with the mobile map, but stated that there should be a careful selection of which types of buildings / landmarks should be included in the map. In iGo My way v.8.0, for example, they found the screen overloaded with too many 3D buildings making it difficult and slow for them to use the map. At the same time, the similar colours that were applied to the different buildings made it often impossible to understand which one is the building that they were looking at, even in front of them. Most TPs argued that a pop-up photo of a landmark would be more helpful (and less CPU power–consuming) than their 3D representation. In this regard, photos of corner buildings would be critical for the orientation of TP7, as they would allow fast selection of the correct streets. Continuously visible house numbering would also be helpful for orientation and navigation, together with a very accurate street size / pattern visualization according to reality. Including railroads, building blocks and pedestrian paths was considered to be important by many TPs as well.

In many cases, TPs could not properly connect landmarks of reality to the mobile map displays, as they were either not visible at all on the latter, or they were appearing and disappearing in different zoom levels. Sometimes they were not represented in an easily perceivable form. As it comes to the "mental" landmarks of the users, things were a little bit more complicated. Next to the representation issues already mentioned, the development of their mental maps based on landmarks was decelerated by their looking at the mobile screen most of the time. The majority of TPs argued that if they had used a paper map (or no map at all) they would have developed, combined and memorized more landmarks.

Despite all this, TPs did use landmarks as points of connection between reality and its graphic representation in the form of mobile maps and they tried to orient the mobile map towards the position and direction of the real landmarks. This was problematic in areas where there was low diversity of structural elements in the environment. The TPs got confused / disorientated many times when they were trying to rely merely on the position arrow on the map, as this is not a very accurate navigation tool at walking speeds. It appeared that most TPs found the position arrow on the mobile maps very important, and complained about its inaccuracy in showing the actual direction of movement. They made mistakes during navigation because they tried to follow the arrow, despite the fact that they were continuously informed by the researcher not to rely exclusively on that and try to find other sources of information to understand where they are. The problem is that GPS signal-based position arrows on mobile maps cannot work reliably when the speed of movement is low, as what is happening during pedestrian navigation. Obviously, the TPs would prefer a map continuously rotating towards the direction of their movement and towards their point of view when they are not moving.

A last issue related to personal geo-identification and navigation is the sequential need for overview and detailed map displays. Although iGo My way v.8.0 has smooth zooming capabilities, none of the participants noticed that during the tests. The possible reason for this finding is that in densely built up areas, such as Amsterdam, the software cannot process the geographic data fast enough in a common mobile device in order to achieve graphically smooth changes during zooming-in and out. This technical problem was also considered in the UWSM2 project.

During the tests, most of the TPs found it easier to keep an overview map of the area in their minds while inspecting a more detailed view. However, they agreed that frequent zooming-in and out is required in order not to lose the contact between reality and the maps in their minds. In case of a total loss of the GPS signal, as a consequence of which they would have to find their way through a static mobile map, most TPs would use the road names and the street sizes and patterns in order to first understand where they are and then navigate.

4.10 Conclusions

This chapter presented the UCD-based methodological plan that is applied in this research in order to design and develop a usable mobile navigation interface for pedestrians who visit unfamiliar urban areas. As part of the UCD Requirement Analysis stage, the findings of a field-based experiment executed for defining the requirements of this particular group of users were presented. That experiment investigated the interactions of visitors to unfamiliar cities with the environment, their mental maps and the (carto-) graphic interface of two existing geo-mobile applications. The experiment applied a combination of qualitative research methods and techniques supported by a special technical solution for field-based user research.

Some of the results that could directly contribute to making guidelines for more usable geo-mobile applications are the determination of the types of landmarks that support user geo-identification and should be included in mobile map interfaces and the representation of these landmarks as a combination of unique icons and popping-up windows showing pictorial and text information.

Determining the map scales at which particular types of landmarks should remain visible or at which their visual characteristics should be changed depending on the user's requirements and preferences and the context of use is one of the issues to be addressed. Minimizing the need to use the zooming function by properly selecting and visualizing important structural components including landmarks and by applying user-friendly zooming techniques is another one.

The results of this chapter build the foundation upon which a detailed user task analysis can be done in order to model user-interface interactions, define information and system requirements and propose design solutions for the development of a new prototype interface. These successive design activities will be the subject of Chapter 5.

5. Conceptual design and prototype implementation

5.1 Introduction

Investigating the behaviour of users of geo-mobile applications in a real context setting revealed a lot of information regarding the types of important landmarks for orientation and navigation (see Chapter 4). It also disclosed the way they use them and their preferences about the representation of these landmarks on the mobile maps amongst other important things. The users followed a particular course of actions during the experimental tasks, beginning with an effort to geo-identify themselves in a new place and finishing by reaching their final destination.

The actions of the users during their orientation and navigation tasks required particular information in order to be completed, answering the specific (geographic) questions that they had. To get a better understanding of the interactions between the users, the environment and the mobile map when answering those questions, a user task analysis was executed and will be reported on in this chapter.

Task analysis helped identifying the problems of the users with current navigation systems and their information requirements when executing orientation and navigation tasks. These were transformed into use case models on the basis of which the system design requirements of a usable prototype were determined and its functionality further analysed. Using the results of this analysis, a series of UML-based sequence diagrams was constructed. UML (Unified Modelling Language) is helpful in transferring the conceptual designs of systems into prototypes by recreating visual, high-level models of the configuration and functionalities of the system. These models allowed for the implementation of the software code of the prototype using suitable software and hardware tools. However, there were also several issues that had to be addressed during the software implementation. The solutions that were applied in order to solve those issues, as well as the reasons behind the selection of particular solutions are presented at the end of this chapter. A general diagram of the order of actions that was followed and will be presented in this chapter is shown in Figure 5.1.

Figure 5.1: Followed course of actions, as presented in this Chapter 5.

5.2 Task analysis

As the goal of the UCD-based approach followed in this research is the design and development of a mobile cartographic interface that supports orientation and navigation of pedestrian visitors to unfamiliar urban areas using landmarks, the questions that these users pose to the interface must first be formulated. These questions would be ideally answered by the system in a clear and straightforward way, providing the user with information important for the planning and execution of his or her navigation activities. At the same time, the design of the interface should follow well-defined rules regarding the presentation of information in a usable form.

Considering these facts, the first step is to investigate the questions that the users have, the problems of current systems to answer these questions, the sources of possible confusion and the involved user-device interactions. The user is the centre of focus in UCD methodologies, implying that his or her profile, tasks, goals and interactions should be potentially understood and modelled in order to drive the conceptual design of solutions. The task-based user experiment that was carried out in the area of Amsterdam as part of the requirement analysis stage provided a lot of valuable information regarding the above aspects. The results of this experiment, together with the findings of an earlier study (Delikostidis, 2007; van Elzakker et al., 2008), helped building a list of current systems' problems and formulate the prerequisites and requirements for a more usable pedestrian navigation interface design for the given pedestrian context of use (Delikostidis & van Elzakker, 2009a; Delikostidis & van Elzakker, 2009b; Delikostidis & van Elzakker, 2009c).

The experiment as described in Chapter 4 was based on a scenario of a traveller visiting the centre and the suburbs of a tourist city (Amsterdam), reflecting a real-context orientation and navigation activity. Scenarios are descriptive stories that portray use instances under specific situations involving a single or many actors sharing a common aim and they outline the succession of steps and incidents that lead to that aim (Carroll, 2000). From the analysis of scenarios, first the higher and then the lower level tasks and information requirements can be derived, which can form the basis for the conceptual design of an interface prototype. In order to serve this aim, a more realistic view of the user activities is required, implying that more detailed scenarios should be constructed. Considering that fact, the general scenario used for the experiment was reformulated into two new scenarios, adjusted to the special settings of each area where the experiment was executed:

Scenario no. 1: John arrives at the central "Dam Square" in Amsterdam, a tourist city that he has not visited before, after walking from the city's central train station. The aim of the trip is to find and go to the Biblical (Bijbels) Museum. Then he is planning to have a look at a music theatre, named Doelenzaal that he heard a lot about. Although there is enough time to carry out this itinerary, he does not want to take big rounds but walk a route that includes some possibly interesting places along. Besides, he is interested to collect as much information as possible regarding the city plan so that he can easily find his way back to the starting point (Dam Square). There he can spend some time around for shopping and eating a meal before returning to the train station for the trip back to his city of residence. The acquired knowledge of the area can also be useful in a future trip to the same place.

Scenario no. 2: Mary exits the Metro station "Wibautstraat" in Amsterdam, facing an area that she has not visited before and which is mainly used for housing and industry. The aim of the trip is to find and go to an "Albert Heijn" supermarket which is very close to a square / park named "Krugerplein". There she wants to meet a friend to whom she wants to return a book that she has borrowed and also buy some food. Together with her friend they are planning to go to café "Dauphine" (which is close to Metro station "Amstelstation") afterwards where they can have a coffee and talk before she takes the metro to go back to the area of Amsterdam where she is staying. As she is busy with many things, she does not want to spend too much time to finish this itinerary, and, thus, she tries to select the shortest path including possible shortcuts. She is particularly interested to learn this route, as she wants to find her way fast in case she has to do the same trip in the near future.

Although the two scenarios have many differences, there is a sequence of high-level steps that are crucial for the completion of both of the scenarios' goals, related to specific questions that the users have during each of the steps. Based on the scenarios, the sequence of steps involving the use of a mobile navigation system as a supportive tool would be as follows:

1. The user enters an unknown urban area and tries to orient him or herself with the help of the mobile map.
2. The mobile map shows the current position of the user and an abstract form of reality surrounding the user.

3. The user is panning and zooming-in / out the map, linking reality, mobile map and his or her mental map, in order to acquire spatial awareness of the place.
4. The user proceeds with steps 2 and 3, until satisfied.
5. The user searches for his or her destination point on the mobile map using zooming and panning functions and decides on a possible route towards that destination.
6. The map shows the current position, global or detail view of the area and any available information.
7. The user proceeds with steps 5 and 6, until satisfied.
8. The user confirms correct route following, controls the route to avoid mistakes and reorient him or herself otherwise.
9. The map shows the current position, global and detail view of the area and any available information.
10. The user proceeds with steps 8 and 9, until satisfied.
11. The user is seeking for confirmation of destination.
12. The map shows the current position, global and detail view of the area and any available information.
13. The user proceeds with steps 11 and 12, until satisfied.

The above sequence of steps outlines the process of orientation and navigation in a general matter. Transforming these steps into user tasks (T) would result into 4 main ones:

1. Initial Geo-identification (T1)
2. Identification of Destination and Travel Decision (T2)
3. Route Confirmation / Route Control / Reorientation (T3)
4. Destination Confirmation (T4)

These tasks and the related main questions are presented schematically in Figure 5.2 and a more detailed description of each of them is given afterwards.

Each of the tasks is described in more detail based on the available experimental results:

Initial Geo-identification (orientation) (T1):

This is the very first task of any navigation activity, i.e. understanding one's location with reference to the surroundings using a mobile map which is aligned based on position and orientation sensor information (e.g. GPS). The goal of this task is to acquire a global understanding of the current position and the surroundings. This is done through orienting in map, reality, and mental map terms, by comparing, combining and linking information from every possible source.

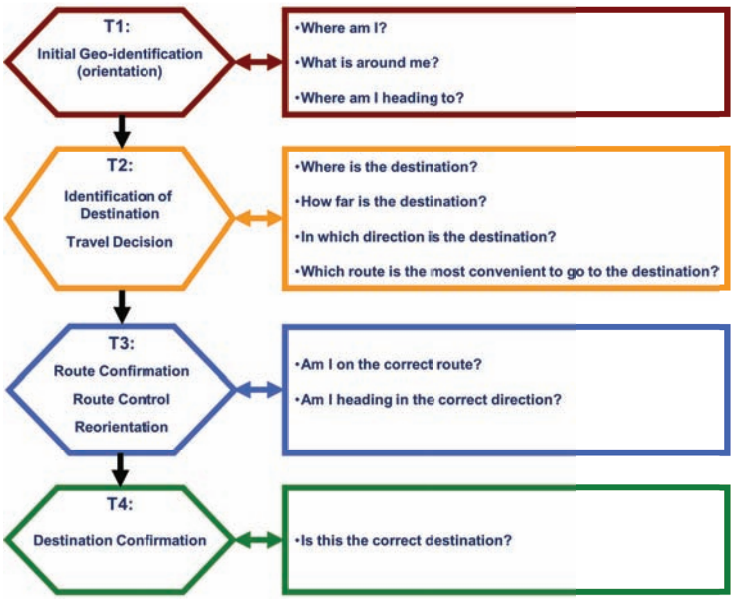


Figure 5.2: Orientation and navigation tasks and related basic user questions.

The core questions (Q) that the user poses during this task are:

Q1. Where am I?
Q2. What is around me?
Q3. Where I am heading to (and what exists there)?

In order to answer these questions, the user inspects the following information sources (I):

I1. His or her position on the map (looking at the position / orientation arrow).
I2. Mostly a North-up overview map of the area but also a heading-up map to verify heading if such an accurate map is available (continuous map orientation towards the user's viewpoint without the need of user movement).
I3. An overview and then a detailed map of the area (by zooming-in and panning).
I4. Street patterns and sizes on the map compared to the ones in reality.
I5. Possibly available street names, numbers or other signs (e.g. square names) in reality that can be compared with the ones on the mobile map.
I6. Visible landmarks around his or her position both on the mobile map and in the surrounding environment.
I7. Additional information regarding landmarks around the current position.

The problems (P) that appeared during this task in the requirement analysis experiments were:

P1. Position / orientation arrow inaccuracies (due to GPS signal interruptions in urban canyons).

P2. Street patterns and widths (and also colouring based on street width / type) not related to reality.

P3. Symbology and naming of landmarks useful for orientation missing from mobile map or not eligible.

P4. Surrounding landmarks missing from the map, existing on the map but not in easily perceivable form, or not verifiable as they are out of visibility of the user in his or her current position.

P5. Wrong spatial comprehension / estimation of distances, patterns and sizes due to wrong comprehension of / absence of / illegible map legend indication.

P6. Wrong spatial comprehension / estimation of distances, patterns and sizes due to unavailability of concurrent overview and detailed map information and the need for continuous zooming-in and out.

P7. Wrong spatial comprehension / estimation of distances, patterns and sizes due to non-smooth transition between zoom levels.

P8. Landmarks around current position missing from the map or missing in particular zoom levels, or: existing on the map but not in an easily perceivable form, or: cannot be verified as they are out of visibility of the user in his or her current position.

P9. Additional information regarding landmarks around the current position unavailable (in graphical, photographical, or text form e.g. historical, architectural or other facts).

Identification of Destination and Travel Decision (T2):

After completing the first task of initial orientation, the destination of travel has to be identified and a route that leads to this destination has to be selected. The goal of this task is to determine which route is the most convenient considering different facts. These are the location of the destination in relation to the current position, the route costs (e.g. time, distance), the benefits (e.g. route quality and interest) and the purpose of the trip (e.g. sightseeing, direct navigation to the destination via shortest / fastest / safest / nicest path, or navigation to destination via particular stop point(s)). The core questions that the user poses during this task are:

Q4. Where is the destination?

Q5. How far is the destination?

Q6. In which direction is the destination?

Q7. Which route is the most convenient to go to the destination?

In order to answer these questions, the user inspects I1 and I2 (see above) and, additionally:

I8. The position of the destination on the map.
I9. The direction in which the destination lies in reality and on the map.
I10. Possibly recognizable landmarks towards the direction of the destination on the map and in reality in order to confirm the destination direction and position.
I11. Any possible route that leads to the destination, taking into account the particular context of travel (e.g. sightseeing) from the user's perspective.
I12. Extra information about the destination, if available (e.g. photos and text).

The problems that appeared during this task in the requirement analysis experiments were P1, P3, P5, P6 and P7 (see above) and, additionally:

P10. Destination position not indicated and symbology cannot be adjusted on the map.
P11. Landmarks towards the destination are missing from the map or missing in particular zoom levels, or are existing on the map but not in an easily perceivable form, or cannot be verified as they are out of visibility of the user in his or her current position.
P12. Additional information regarding landmarks towards the destination (in graphical, such as photos, or text form e.g. historical, architectural or other facts) unavailable.
P13. Additional information regarding the destination unavailable (in graphical, photographical, or text form appearing as pop-ups).

Route Confirmation / Route Control / Reorientation (T3):

After finding out the current position in both the mobile map and reality and conceptualizing that position inside his or her mental map, the user follows the route that was planned during the previous task. The goal of the task described here is to keep control of the route in order to avoid mistakes and unnecessary round-trips. Thus, whether being on the correct track that leads to the destination or not, is something to be confirmed at particular time / distance intervals. If the user is on the correct track, the navigation continues until the next point of confirmation, which is usually a decision point such as a multiple-direction street intersection. If the user is not on the correct track, he or she has to reorient him or herself through a process identical to the first navigation task described earlier (T1). However, at this point landmark and route knowledge has already been acquired and this decreases the difficulty of reorientation in most of the cases. In order to avoid multiple reorientations which cost time and distance, the user should keep good control of the route which depends amongst other things on the accuracy of the information he or she is provided with via the mobile map and his or her orientation and navigation abilities. The core questions that the user poses during this task are:

Q8. Am I on the correct route?
Q9. Am I heading in the correct direction?

In order to answer these questions, the user inspects I1, I4, I5, I6, I7, I8, I9, I10 and I11 and, additionally:

I13. Mostly a heading-up detailed map of the area during navigation (that can be transformed to North-up when needed) to help acquiring global awareness especially during reorientation.
I14. A detailed and then an overview map of the area (by zooming out and panning).

The problems that appeared during this task in the requirement analysis experiments were P1, P3, P5, P6, P7, P8 and P11.

Destination Confirmation (T4):

This is the final task of a navigation activity, when the user arrives (or thinks that he or she has arrived) at the planned destination. The goal of the user during this task is to confirm whether the current point is the correct destination, by comparing, combining and linking information from every possible source. The core question that the user poses during this task is:

Q10. Is this the correct destination?

In order to answer this question, the user inspects I1, I4, I5, I6, I7, I8, I11, I12 and I13. The problems that appeared during this task in the requirement analysis experiments were P1, P5, P6, P7, P8, P10 and P13. Considering both the information needed by the users to complete each task, but also the problems that they had to do so, their (geographic) information requirements (which will be referred to as IR here) can be formulated (Table 5.1).

5.3 Additional information requirements

The type of important landmarks used for orientation and navigation depends on the area (e.g. water features such as canals are very important for Amsterdam city centre), the user's profile and the context of use (e.g. for tourist sightseeing trips monuments and museums are of high importance). But at the same time, globally visible landmarks (tall buildings and routemarks such as train tracks) are constantly observed and support developing landmark and route knowledge. Although selecting specific types of landmarks (to be presented on a mobile map) based on individual user preferences would further personalize a navigation interface, there are still many difficulties for doing so. If this information is captured manually, as for instance through selection menus and check-out boxes, this would increase the complexity of use of the interface and the time needed before it is ready for use. Besides, the user's direct input could result in additional navigation problems, if not utilized carefully. For instance, the user could decide to exclude all the landmarks except the restaurants from the map, if that is possible, when he or she is searching for a place to eat. This would then dramatically decrease the amount of spatial references available to the user, increasing the possibilities for orientation confusion and mistakes. On the other hand, automatic determination of user preferences based on e.g. sensory data or navigation history would require long-term use of the interface before it starts producing usable results.

N	Information Requirement	Task			
		Initial Geo-identification (orientation) (T1)	Identification of Destination and Travel Decision (T2)	Route Confirmation / Route Control / Reorientation (T3)	Destination Confirmation (T4)
IR1	Accurate and legible current position and orientation	✓	✓	✓	✓
IR2	Interchangeable North-up map / heading-up	✓	✓	✓	✓
IR3	Map with zooming and panning capabilities	✓	✓	✓	✓
IR4	Street patterns and sizes on the map reflecting reality	✓	✓	✓	✓
IR5	Street names, numbers and place signs on (detail) map	✓	✓	✓	✓
IR6	Visible landmarks around current position on the map	✓		✓	✓
IR7	Legible position and symbology of the destination on map		✓	✓	✓
IR8	Direction of destination directly provided on the map		✓	✓	✓
IR9	Visible landmarks in the direction of destination		✓	✓	
IR10	Different routing possibilities based on user's decisions		✓	✓	✓
IR11	Additional information regarding destination		✓	✓	✓
IR13	Legible symbology, naming and information for landmarks	✓	✓	✓	✓
IR14	Legible map scale indication	✓	✓	✓	✓
IR15	Smooth zooming capability	✓	✓	✓	✓

Table 5.1: Information requirements for orientation and navigation task execution.

A third, feasible approach -building a basic set of important landmarks based on accumulative experimental results for a particular context provides a common ground, which is suitable for most of the individual users. The presentation of this set on the mobile map could then be adapted depending on general contextual factors such as position, orientation, and time availability of the user. The latter is an especially important factor which affects a trip in terms of execution time, distance to be travelled, number of places to visit and route possibilities, amongst other things. In the two scenarios presented at the beginning of the previous Section 5.2, this fact was clearly evident. Time availability can be considered as part of the user's profile.

The position and orientation of the user determine which landmarks are visible in reality and it would be very helpful for the user in order to orient him or herself and navigate if this information was also provided by the mobile interface. For instance, when the user is looking in a particular direction in reality, he or she can see only the nearby (local) landmarks that are inside his or her field of vision. At the same time, global landmarks, such as very tall buildings, could also be visible in a particular direction, but many times this is not possible because there are other buildings or other massive objects that block that view. Providing the users with information regarding the visibility of global landmarks, which comprise very distinctive spatial reference points, would help them align reality, mobile map and their mental map with less effort. Further, they could also find their destination(s) more easily especially if the direction of specific landmarks was somehow referenced to the direction of the destination on the map.

Time available to complete a navigation activity is one of the most important aspects of the user's profile which has not been sufficiently considered yet in geo-mobile applications. Providing the users with routing information depending on their time availability would help them make better travelling decisions and planning. At the same time, placing local landmarks along the routes would help users continuously verify their position and orientation and control their movement more precisely. Time availability as a contextual factor for map adaptation is something that new interfaces should encompass.

Considering all the above, the selection of important local and global landmarks in this research will be based on the results of the requirement analysis experiments, focusing on the context of use involved. Following the same UCD-based procedure, it would also be possible to identify the important landmarks for different contexts, as for example for navigation in rural areas or theme and natural parks.

The findings of the requirement analysis experiments suggested also that availability of recent track records helped users to recall previous routes, mistakes and important points. However, in currently available navigation systems this information is usually presented in a way which continuously overlaps itself without providing distinguishable individual track characteristics (e.g. time of recording, speed) and becomes virtually meaningless in the end. User-selected track presentation criteria and automatic track shaping (using track colour intensity and width as indicators) are examples of more descriptive presentation approaches. This would be an information requirement to be potentially considered when conceptually designing a prototype interface later on in this research.

An overall conclusion of the requirement analysis experiments was that the users disliked the idea of being provided with vehicle navigation system-like route instructions. They prefer to use the mobile navigation system as a flexible supporting tool and not as a source they should solely rely upon. The latter would lead to insufficient development of their mental maps of the area and would decrease the chances of finding their way in cases when the system malfunctions or is not available (during a current or future trip to the same area). This is in line with the findings of other research studies (Brown & Chalmers, 2003; Wealands, 2007). Further, many alternative paths, accessible to pedestrians, are absent from current mobile navigation systems. This costs the users unnecessary travelling time and distance, and is, at the same time, reducing their trust in these systems. Providing users with multiple possibilities of routes to their destination(s) is another important information requirement.

5.4 Use case modelling of user interactions

In order to build the foundation upon which the conceptual design of a prototype mobile cartographic interface for navigation in unfamiliar urban areas could be developed, the system responses to particular user requests should be modelled. One of the ways to do that is by using UML. Following this approach, we first identify the actors, who are the ones (humans or things) that are making use of the system and interacting with it while playing particular roles. These actors require the system to perform particular actions, which are defined as use cases. The latter can be established by means of investigation of any possible section of the actor-system interactions. For example, this could be done by distinguishing the specific operations that are needed by particular actors and identifying different storing and recalling capabilities of the system induced by any actors. Any system state change indication to the actors and possible outward activities which influence the system could also be reported and ways of alerting the system to handle these activities could be established. (Arlow & Neustadt, 2002).

From the task analysis that was done in Section 5.2, four orientation and navigation tasks were distinguished. These can be directly converted into four use cases accordingly: “Get orientation information”, “Select destination and obtain route”, “Keep on route to destination” and “Confirm arrival to destination”. Considering also the importance of time availability as part of the user’s profile, as discussed in Section 5.3, one more use case could be developed as well: “Change user profile”. Putting together the actors who comprise external entities to the system (presented in the form of a box) and the use cases, which represent the actual behaviour of the system, the following overall use case diagram “Orient yourself and navigate to destination” can be created (Figure 5.3).

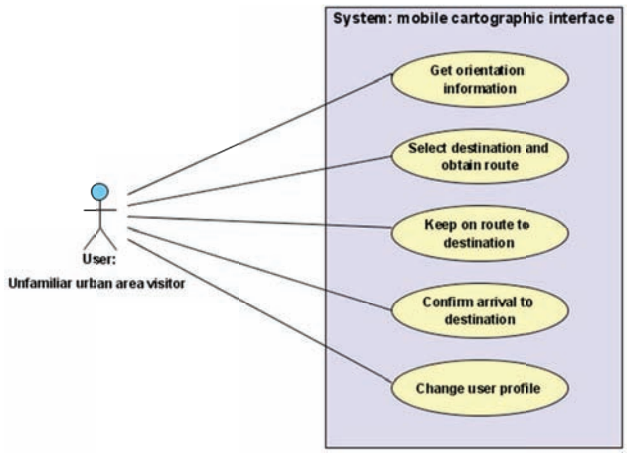


Figure 5.3: Overall use case diagram “Orient yourself and navigate to destination”, consisting of five smaller use cases.

Each of the five use cases can be modelled in the form of graphical workflows, representing the stepwise course of actions involved and the logic sequence between them. This is done here using UML activity diagrams. In Figure 5.4, the activity diagram of the sub-use case “Get orientation information" is shown. The user actions are on the left and the responses of the mobile device on the right, separated with a dashed red line. As depicted in this diagram, after the user is provided with a North-up overview map where his or her position is shown, he or she can select a different map orientation (heading-up) or keep the North-up map. Depending on the decisions of the user in particular, condition-based decision points represented by a diamond, the mobile device (system) returns different results. For example, if the user changes the map to heading-up, only the (local and global) landmarks in the direction of his or her viewpoint are shown. If, instead, he or she keeps the North-up map, all the landmarks around his or her position are shown.

The black bars (forks) in the diagram represent points where the flow of actions goes to multiple items in parallel or where different flows end up in the same item. For example, after the user has been provided with a North-up map he or she can either select a different map orientation, zoom in or out the map or get information about one or more of the shown landmarks. Following the same logic, the subsequent activity diagram in Figure 5.5 corresponds to the sub-use cases “Select destination and obtain route" and “Change user profile”.

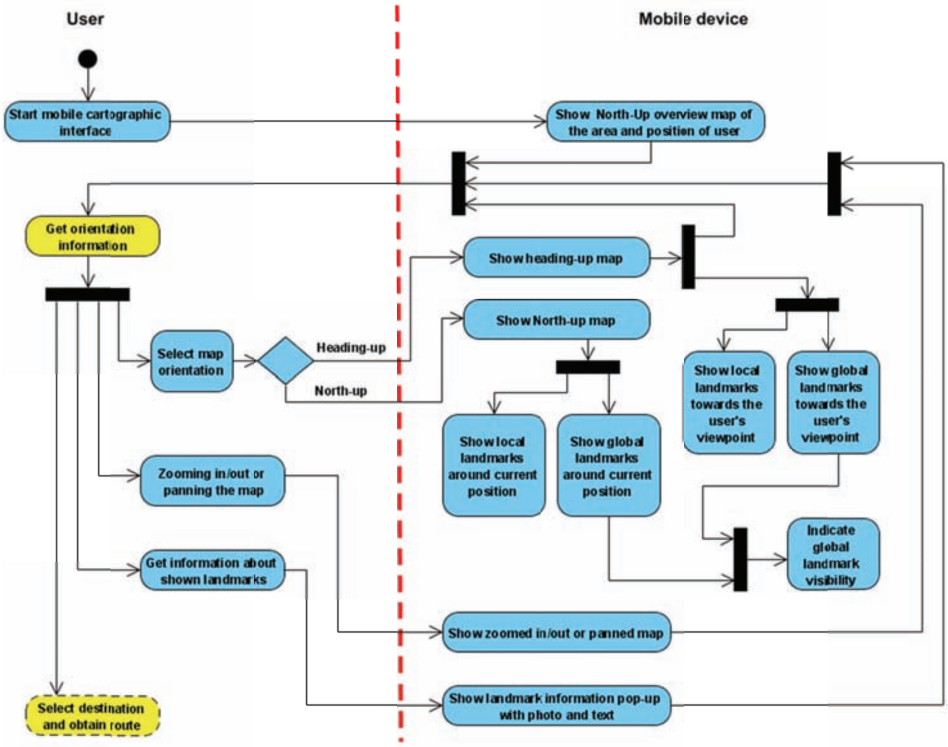


Figure 5.4: Activity diagram of sub- use case “Get orientation information".

A part of this diagram, concerning general functions of the interface such as landmark selection / filtering, landmark visibility indication or zooming and panning is identical to the one in Figure 5.4. However, there is an additional adaptation on the landmark filtering when the rotated map is used and the destination has been selected. In that case, it is not the global landmarks towards the user’s viewpoint that are shown on the map, but the ones that reside in the direction of the destination. In addition to that, the general logic behind the processes of destination selection and route provision is illustrated. These processes are interrelated with the time availability selection as part of the (changeable) profile of the user, resulting in route and landmark adaptation, depending on whether the time available for travelling is little or plenty.

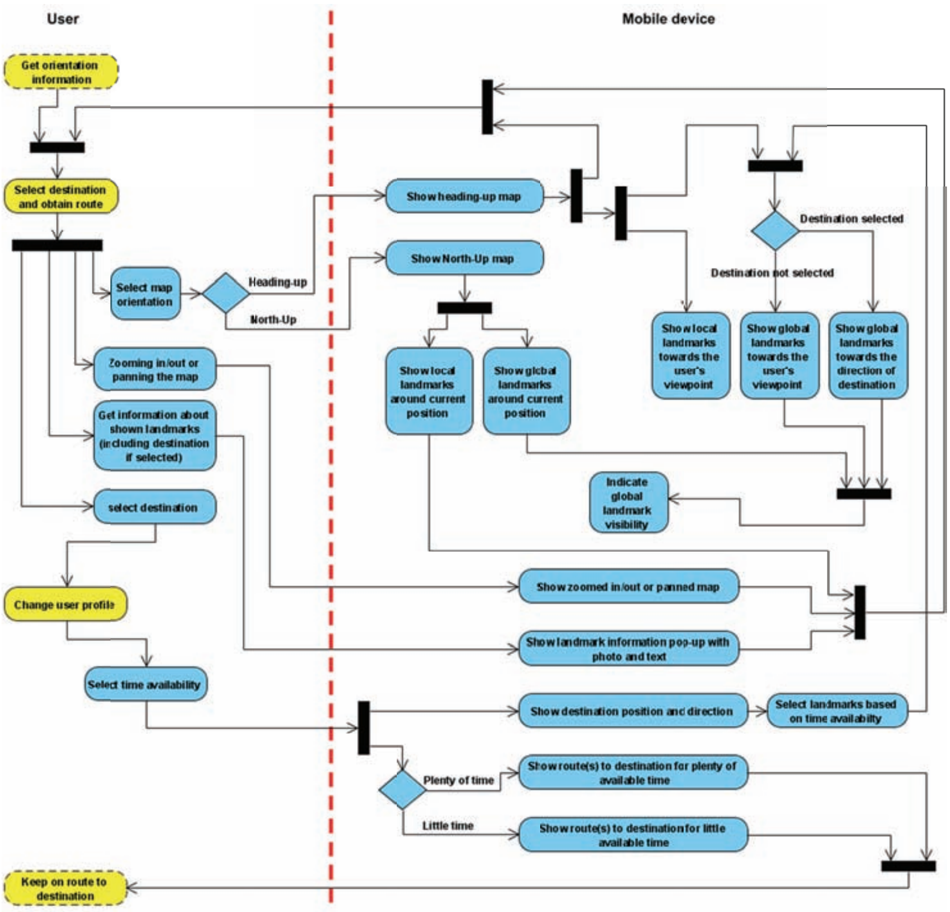


Figure 5.5: Activity diagram of sub-use cases “Select destination and obtain route" and “Change user profile”.

Figure 5.6 illustrates the activity diagram of the sub-use case “Keep on route to destination". This diagram shows flows identical to the ones appearing in Figure 5.5 after the destination has been selected.

Finally, Figure 5.7 exhibits the activity diagram of the sub-use case “Confirm arrival to destination". This diagram shares the general function flows contained in the previous activity diagrams (zooming, map orientation change and so on) but the global landmark filtering when the rotated map is used is the same as in Figure 5.4 and Figure 5.5 (before the destination is selected).

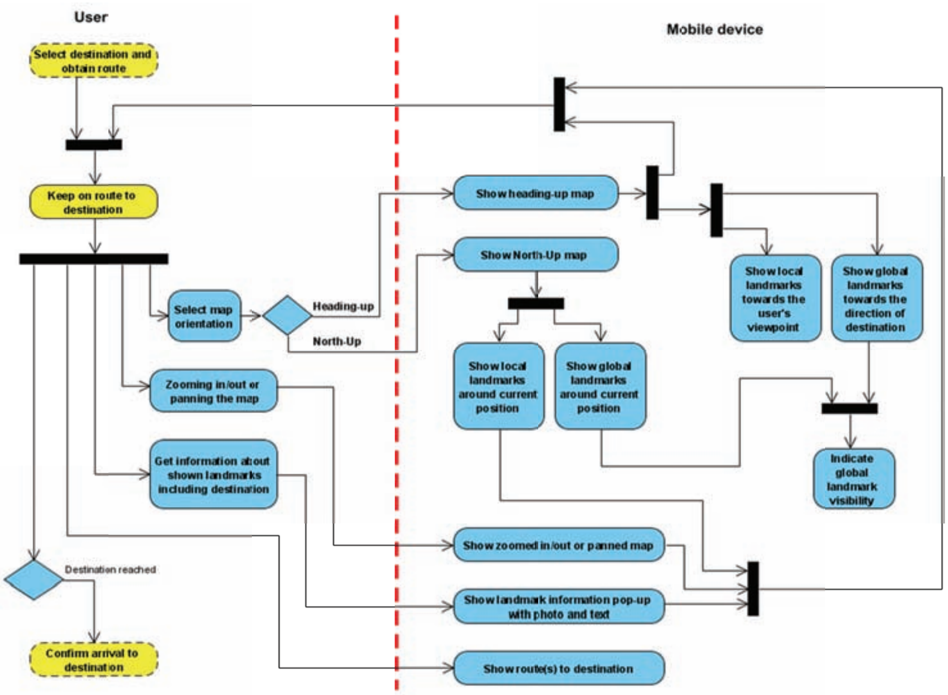


Figure 5.6: Activity diagram of sub-use case “Keep on route to destination".

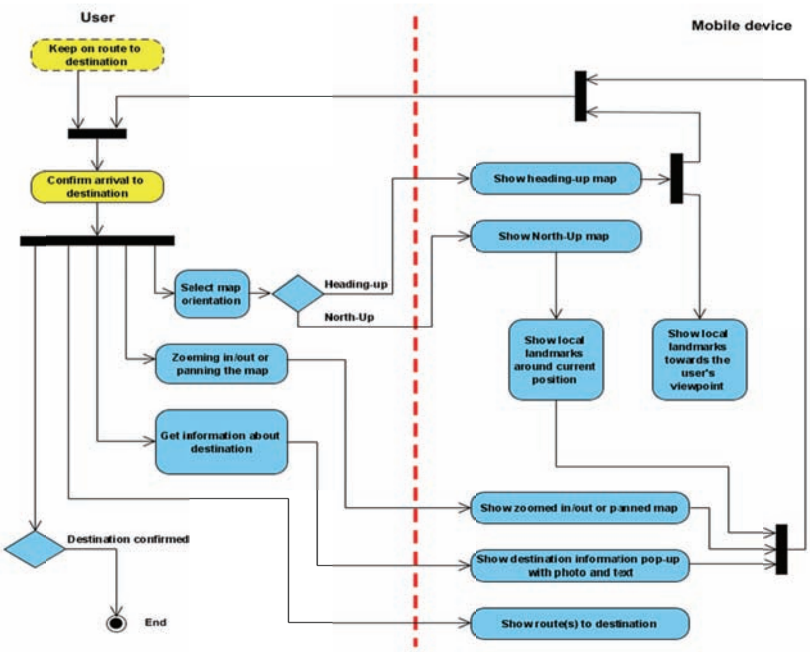


Figure 5.7: Activity diagram of sub-use case “Confirm arrival to destination".

Use case modelling helps acquiring a general overview of the expected functionality of a system aimed at meeting the determined information requirements of the user in this research (see Sections 5.2 and 5.3). Through this modelling, the design requirements of such a system can be distinguished, something that is done in the following section.

5.5 System Design Requirements

A system which would be able to fulfill the identified user requirements on the basis of the user-system interactions established in the use case modelling should embody specific capabilities and functionality. To serve that aim, five required technical features were identified:

1. An accurate orientation sensor even when the user is not moving. The reason: current GPS receiver-based compass measurements are unreliable when the speed of movement is low or zero. Combined with that, more advanced solutions could be used, such as Augmented Reality. Such a solution is used in “Layar” mobile application (URL35). Layar uses the GPS receiver and magnetic orientation sensor of mobile devices equipped with both, to superimpose different information layers on the field of vision of the mobile device (captured by its integrated camera). These layers can be for example icons, photos or 3D models of user-selectable landmarks.
2. An up-to-date extended database of pedestrian paths and a flexible way of route provision to the users based on their time availability. The reason: these would give the freedom of selecting the most convenient route, keeping at the same time the user inside predefined limits (based on his or her time available for travelling).
3. The visibility of global and local landmarks based on the position and orientation of the user reflected on the mobile map in an easily conceivable form. The reason: this is an important aspect for the execution of the described orientation and navigation tasks and, as such, it should be calculated and used as input for landmark adaptation.
4. A new approach for concurrent presentation of an overview and a detail map on the mobile interface. The reason: this should reduce the use of zooming by the users as described and it is not well addressed in current geo-mobile applications.
5. The landmarks should be presented on the mobile interface in an easily recognizable and verifiable form. The reason: with current geo-mobile applications the users get many times disoriented and confused as they cannot link what is visible for them in reality to what is presented on the mobile map.

The above features can be offered through the following proposed technical solutions:

1. Using an (electronic) magnetic compass sensor, which works in combination with GPS (A-GPS) receivers, allows for accurate position and orientation calculations. Outdoor positioning on mobile devices is provided through different technologies which can be network-based (e.g. cellular tower ID location), handset-based (e.g. GPS) or hybrid (e.g. A-GPS). Network–based technologies offer lower positioning accuracy than GPS, in the range of 80 to 3000 metres, and depend on the density of cellular phone towers. Handset-based GPS (Global Positioning System) technologies use dedicated satellite signal reception and they provide a reliable solution with positioning accuracy in the range of a few metres. This accuracy, though, declines in areas with large structural densities. And finally, hybrid A-GPS (Assisted-GPS) technologies are an enhancement over GPS, using data received from both the GPS receiver and the cellular towers to drastically decrease the time needed for the first position fix. Additionally, this approach allows for increased sensitivity over single GPS receivers, performing better in between tall buildings and narrow city streets. Thus currently A-GPS is the most convenient solution for positioning on mobile devices. As it comes to orientation accuracy, however, all of the above positioning techniques fail to perform well when the user of the mobile device is standing still or moves slightly. This happens because the determination of the compass direction of the mobile device is based in this case on the bearing calculation of successive position points. When the distance (metres) that the user of the mobile device covers every second is significantly smaller than the accuracy (metres) of the positioning method used, his or her orientation cannot be calculated precisely. By using an electronic compass, on the other hand, this calculation is performed directly and continuously using the magnetic North as a reference point. Augmented Reality-based solutions are a very promising approach for orientation and navigation support; however their accuracy still depends on the accuracy of the GPS and orientation sensors of the mobile devices. To cope with that problem, pattern recognition could be used, based on an intelligent image comparison / recognition algorithm. Comparing reality, captured by the camera of the mobile device, with images retrieved from databases such as Google Street View would allow for advanced orientation-support functions such as automatic landmark recognition. The latter is a solution that should be tried if that is technically possible.

2. Given that pedestrian path network datasets are continuously updated, the users can be provided with a network of paths between starting point and

destination limited by a predetermined buffer (based on user profile information, such as his or her travelling time availability). Any walkable area, including open and closed spaces without dead ends would be regarded as a pedestrian "flow channel" that may lead to the destination. A (simple) example of such a flow channels approach is shown in Figure 5.8.

Figure 5.8: A city road network map with pedestrian "flow channels" visible.

3. There are frameworks under development which can calculate landmark visibility for a given geographic area of interest. These frameworks export their results in the form of map layers which could be utilized by a mobile navigation interface. Using a 3D city model, the visibility of each landmark for successive position points is determined. A layer of landmark visibility (the church in the right hand top corner in this case) is shown in Figure 5.9.

Figure 5.9: Theoretical example of a landmark visibility map layer. Walkable areas where the landmark is visible are presented in a lighter (yellow) colour.

4. Using a reverse overview+detail map, where the surroundings of the user's current position can be shown in greater detail in a freely movable "viewport" window clearly related to the part of the overview map that is shown as background would be in line with the needs found during the requirement analysis experiment. During that experiment, the majority of the users stated that they would easily keep in their minds a previously observed overview map of the test area while inspecting a detailed map view after performing zooming-in. Doing the opposite, e.g. keeping in their minds a previously observed detailed map view while inspecting an overview, zoomed out map would be more difficult for them. They also argued that they would prefer to have an overview map at the same time when they observe the detailed map view without the need to use the zooming-out function.

Figure 5.10: Theoretical example of a reverse Overview+detail map view.

5. Given that the landmark visibility is very important for the orientation and navigation of the users and any landmark photos will help to easily recognize them, these photos should represent what the user actually sees in reality. When a landmark is approached from different directions, what is visible to the user can differ dramatically. For example, a photo taken from the front side of a church or a monument could be totally unrecognizable for a user that approaches that landmark from the sides or the rear part of it. This problem can be solved if multi-perspective photos of the same landmark are available and are provided to the user depending on his or her view angle towards the landmark.

In view of the information requirements of the users regarding the change of the map view from North-up to heading–up and vice-versa during different tasks, it would be interesting to test the solution of automatic map rotation provision. For example, a North-up map would be initially provided to the user when he or she is inspecting the unfamiliar area. If movement of the user towards a straight line is sensed, the interface would change the map to heading-up, or, it would propose that change to the user and would wait for positive or negative response. Together with this automation, it should be always possible for the user to manually change the map orientation. Sensing the movement of the user through a GPS receiver would not be a convenient solution, as often there are sudden "jumps" of the user position due to inaccuracies and GPS signal propagation errors. This could trigger false system responses and confuse or frustrate the user. An electronic compass would also be unable to correctly sense user's movement in straight lines, as it can only detect rotations around the horizontal axle of the mobile device. To actualize this functionality properly, a different type of sensor would be needed: an accelerometer. This device detects any changes of acceleration in all 3 axes of movement (x, y, z) providing with the use of software-based calculations a direct indication of the state of movement (stopped, moving with a stable speed, accelerating, decelerating and so on). If a software code to parameterize the readings of the accelerometer was implemented, it would be possible to set particular thresholds of user movement activity, triggering the system's map orientation change automation when reached. Although this is not a fundamental system design requirement, it would allow for assessing the usability of a new and untried type of context-aware map adaptation.

With these solutions and taking also into account the information requirements established in Section 5.2, the general system response to the tasks presented in Figure 5.2 would be as indicated in Figure 5.11 (right hand column).

For T1, when the user is trying to orientate him or herself for the first time, the system is providing him or her initially with a North-up overview map where his or her position is shown. The map then transforms to a heading-up one, rotating in the direction of the user's viewpoint. This change of map orientation should be done automatically with the use of the acceleration sensor of the mobile device (when the user starts moving around him or herself for a few seconds) or manually by the user. The visible landmarks around the user's position (in case of North-up map) or in the viewpoint of the user (in case of heading-up map) are shown and information about the visibility of global landmarks is provided on the map.

For T2, when the user is identifying the destination and making travelling decisions, an overview map of the area is shown, including the current position of the user and the selected destination. Any visible landmarks towards the destination are also shown on the map to help the user better understand the position and direction of the destination. Simultaneously, multi-routing information is provided in the form of flow channels towards the destination, letting the user decide which paths to follow to reach his or her target, depending on his or her time availability for travelling.

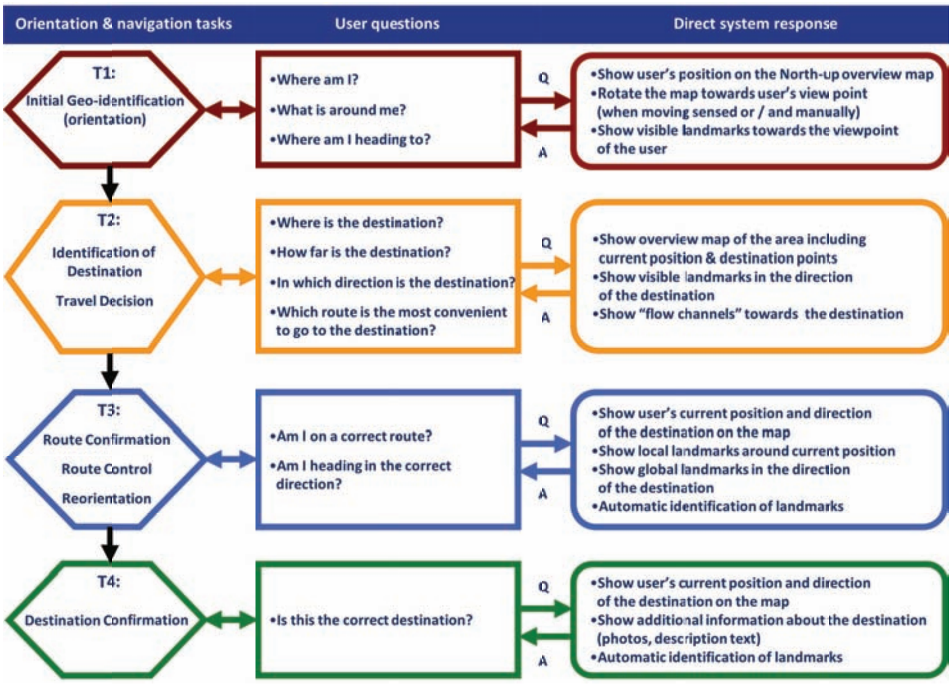


Figure 5.11. The system responses to the user questions for each task.

For T3, when the user is trying to confirm his route, control it and reorient him or herself when needed, the current position of the user is displayed on the map together with a continuous indication of the direction of the destination. The local landmarks around current position and the global landmarks in the direction of the destination are shown, together with the flow channel-based routing to the destination. Automatic identification of landmarks (if possible) further enhances user's performance during this task.

For T4, when the user is trying to confirm his or her destination, the same information as in the previous task is provided, accompanied by additional details regarding the destination in the form of photos and description text.

The above system responses to the user's questions are accompanied by the different technical features described earlier in this section, such as the multi-perspective landmark photos and the reverse overview+detail map.

Providing the users with these types of information, directly related to the questions that they have during each task, it is expected that their orientation and navigation performance will be improved compared to currently available geo-mobile applications. The number of problems that they face linking reality, their mental maps and the mobile map should also be smaller.

Each of the five use cases, now involving the proposed approaches, can be transformed into UML sequence diagrams (Figures 5.12 - 5.16). These diagrams show the user-system interactions in terms of user requests and system module responses over time, presented as directed messages. In this way a detailed insight into the system is provided and this conceptual design can be more easily and directly translated into software code for prototype development.

Figure 5.12 shows a fragment of the sequence diagram of the first sub-use case “Get orientation information”. The system modules (classes) that are involved in the interactions with the user are the interface input (e.g. software and hardware buttons, touch screen), the interface output (mobile screen) the system processing (mobile device CPU), the GPS receiver, the orientation sensor (electronic compass), the acceleration sensor (accelerometer), the map database, the information database (e.g. landmark photos database) and the user profile. For example, when the user asks for a change of map orientation from North-up to rotated heading-up thought the system input (request n. 14), a request (n. 19) is sent to the CPU which returns a response (n. 20) to the interface output in the form of a heading-up map. In order to return this type of information, the CPU continuously requests and receives data from different sensors and databases such as the GPS receiver (request n. 3, return n. 5 and loop n. 6) and the map database (request n. 9 and return n. 10).

Figure 5.13 shows a fragment of the sub-use case 2 “Select destination and obtain route”, Figure 5.14 sub-use case 3 “Keep on route to destination”, Figure 5.15 sub-case 4 “Confirm arrival to destination” and Figure 5.16 sub-use case 5 “Change user profile”. It is not intended to describe in detail the interactions involved in the presented sequence diagrams, as this would exceed the aims of this dissertation. What should be emphasized, however, is their important role as lower-level intermediates between the system modeling (see Section 5.4) and the software implementation of the prototype presented in Section 5.10.

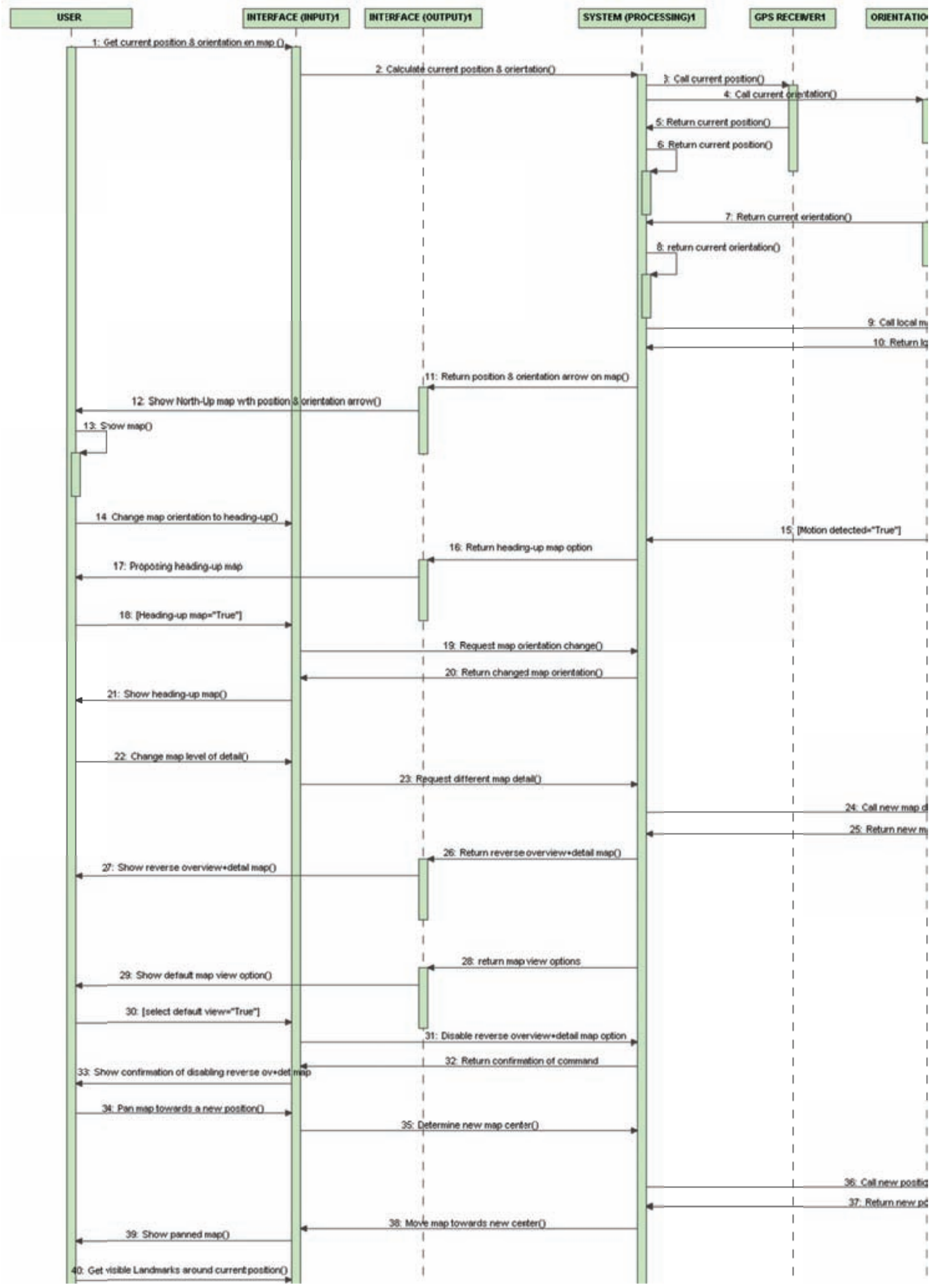


Figure 5.12: Sequence diagram of sub-use case 1"Get orientation information" (partly shown due to space restrictions).

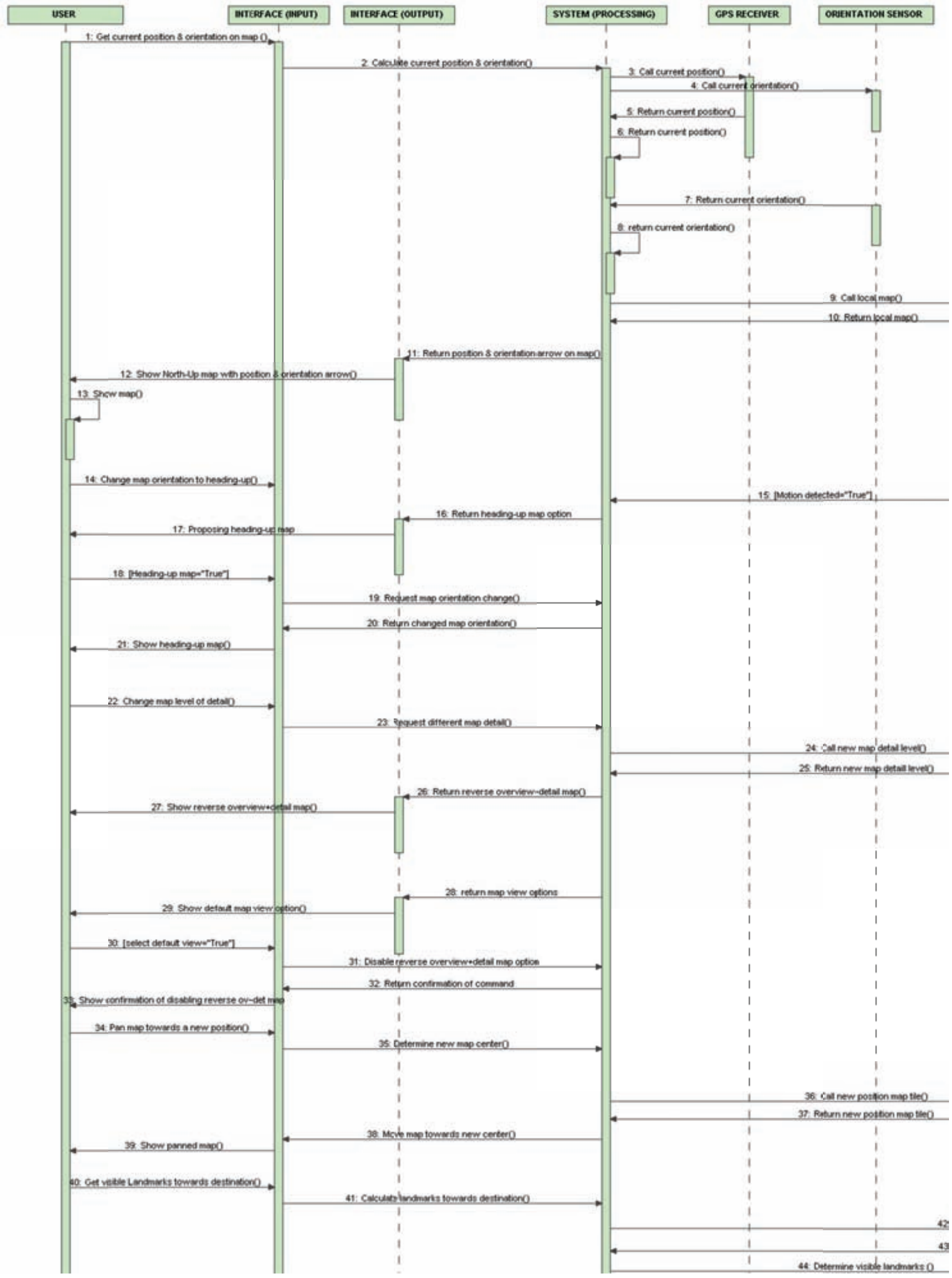


Figure 5.13: Sequence diagram of sub-use case 2 “Select destination and obtain route” (partly shown due to space restrictions).

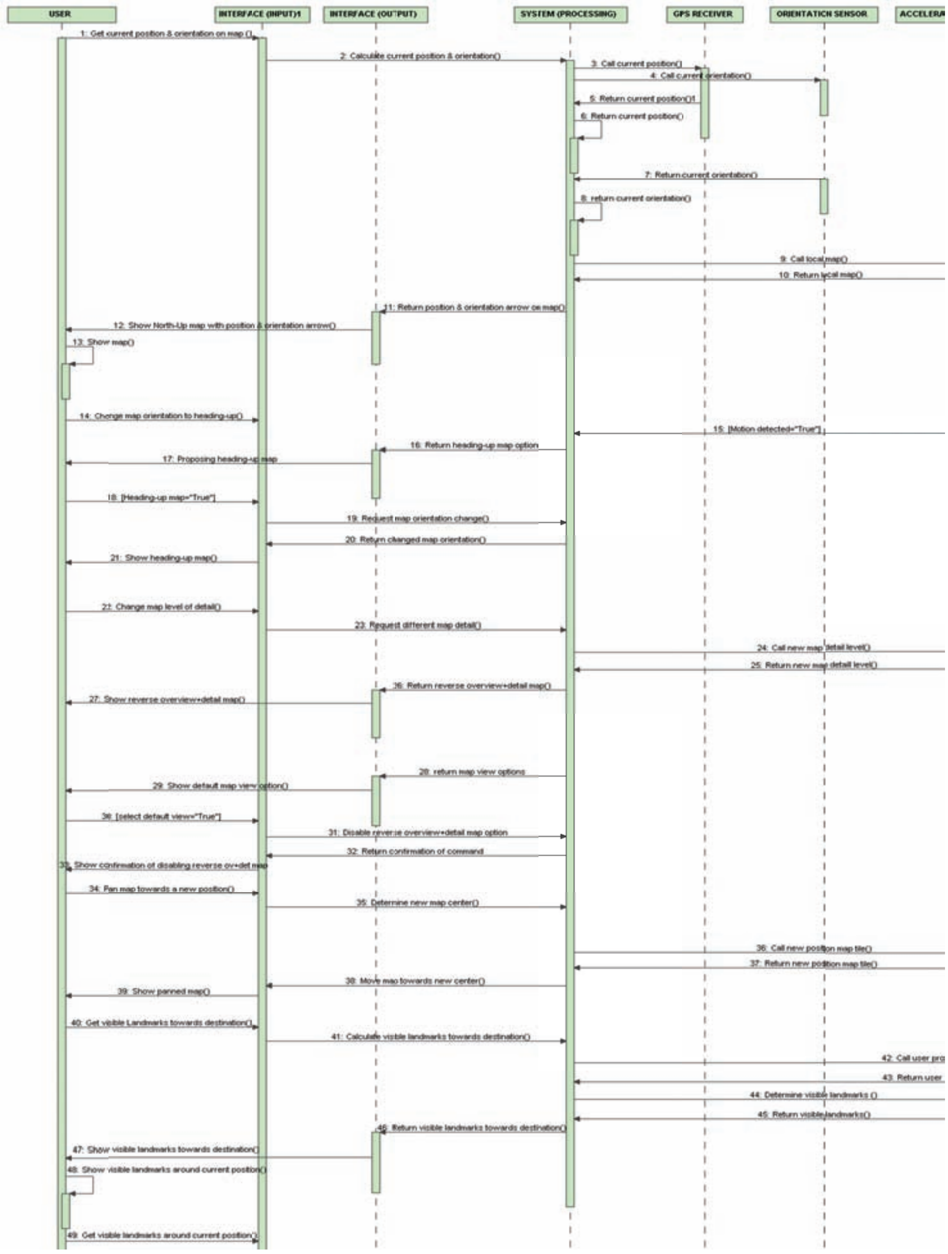


Figure 5.14: Sequence diagram of sub-use case 3 “Keep on route to destination”.

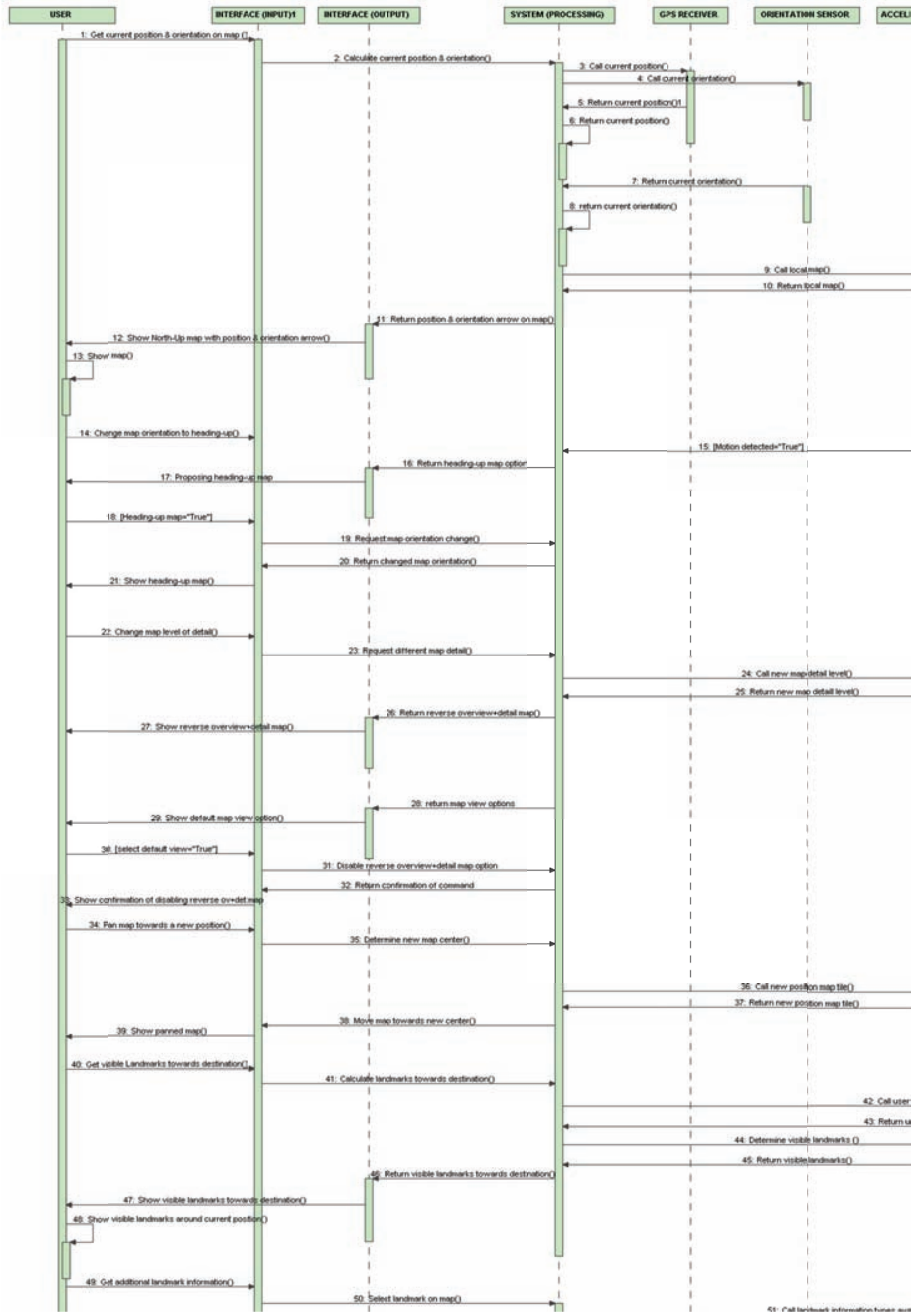


Figure 5.15: Sequence diagram of sub-use case 4 “Confirm arrival to destination”. (partly shown due to space restrictions).

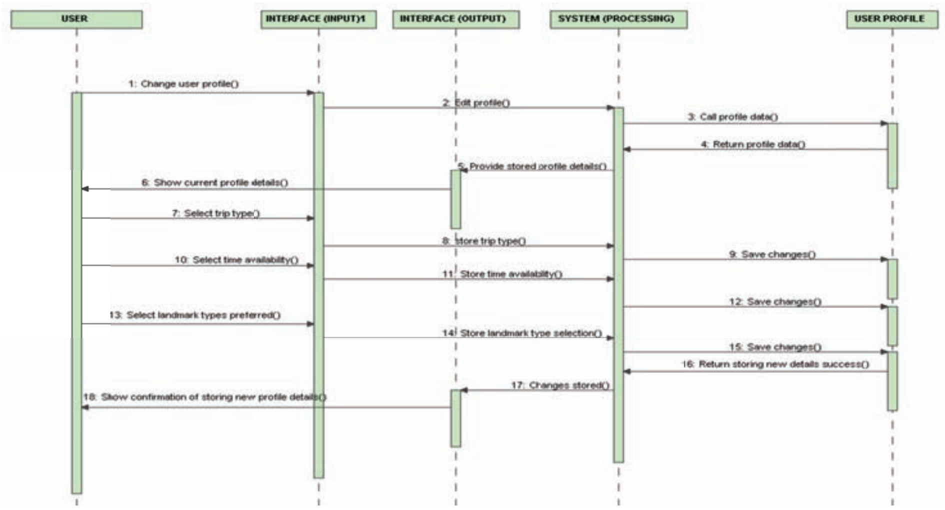


Figure 5.16: Sequence diagram of sub-use case 5 “Change user profile”.

5.6 Proposed interface functionality

In order to build a prototype mobile navigation interface based on the guidelines provided in the previous sections, the different parts and functionalities of the interface have to be described in detail. To start with, the fundamental component of a cartographic interface is the map itself. Building a base map from scratch would not be a convenient approach considering the focus of this research, which is on landmarks and their use as reference points for connecting reality, mobile maps and people’s mental maps. Besides, a smooth map zooming capability is an important aspect of the proposed interface. A good solution would be the use of a freely available base map, such as Open Street Map or Google Maps. On top of these base maps, the prototype interface could be built faster and the proposed functionalities could be implemented. Next to a base map of the whole world, the Google Maps Application Interface (API) provides the tools for building map-based interfaces for different software platforms. Further, that API supports smooth zooming functionality, meaning that the programmer does not have to develop a time consuming solution for that.

5.7 Landmark types and icon design

The selection of landmarks that should appear on the mobile cartographic interface was based on the results of the requirement analysis experiments as discussed in Section 4.9.3. In total, 30 types of important landmarks were identified, which were then categorized into local and global ones. Height was the main attribute considered for making this distinction, and the resulting table was made after investigating the landmarks in the whole city area of Amsterdam. The types of landmarks that could have a height value of >30 meters were then considered as potential members of the global landmark category (Table 5.2).

Nr.	Landmark type	Local	Global
1	Academic / Library	✓	✓
2	Bank	✓	✓
3	Bridge (pedestrian)	✓	
4	Bridge (vehicle)	✓	
5	Bridge (mixed)	✓	
6	City Centre	✓	
7	Church	✓	✓
8	Commercial / office building	✓	✓
9	Fast food	✓	
10	Governmental office	✓	✓
11	Historical	✓	✓
12	Hotel	✓	✓
13	Medical building	✓	✓
14	Museum	✓	✓
15	Noticeable monument	✓	✓
16	Park	✓	
17	Pedestrian crossing	✓	
18	Railroads	✓	
19	Restaurant	✓	
20	River / canal	✓	
21	Roundabout	✓	
22	Sports	✓	✓
23	Square	✓	
24	Station (bus)	✓	✓
25	Station (Metro)	✓	✓
26	Station (train)	✓	✓
27	Stop (bus)	✓	
28	Stop (Metro)	✓	
29	Stop (train)	✓	
30	Residential	✓	✓

Table 5.2: Local and global landmark types.

Following the guidelines provided by related research projects (Elias et al., 2008; Reichenbacher, 2004) but also the results of the requirement analysis experiments, the design of icons representing the landmark types was based on two rules. For the local landmarks, everything except the noticeable monuments would have to be presented with easily understandable, distinct pictograms (see Figure 5.17). The noticeable monuments are here any tombs, memorials or outdoor art objects. These have very distinct and unique visual properties which should be represented on the map accordingly, making it easy to recognize them. For example, a statue in the middle of a square is regarded as a noticeable monument and it should appear on the map as an icon of the same shape and colour in reality. On the other hand, for the types of landmarks that are distinguished based on their function or their brand name more than their visual properties, landmark type icons can be used, as there is no need for unique icons. By using pictograms for these landmarks, it is faster to identify the ones that belong to the same category, for example banks or hotels, depending on the user's information needs at any moment. There is also more icon consistency on the map and less user confusion as he or she is trained to immediately link the pictograms to already experienced types of places. The design of the pictograms was based on existing standard map symbol sets but many pictograms were also uniquely made for the aims of this research. Black and white colour was used for these symbols, except for well-known company logos such as the McDonald's fast-food restaurants and Starbucks Cafés, and transportation stations / stops (bus, metro, train and tram). For the global landmarks, but also the noticeable monuments, either local or global, special drawings were made based on photos of the landmarks in reality, in order to provide direct references to the landmarks' visual characteristics (Figure 5.18). Pictograms were also used for representing some global landmarks, when the landmark could be easily recognized based on its type and functionality. Providing a visibility circle around these landmarks was a simple way to distinguish them from local landmarks.

Figure 5.17: Examples of pictogram landmark icons.

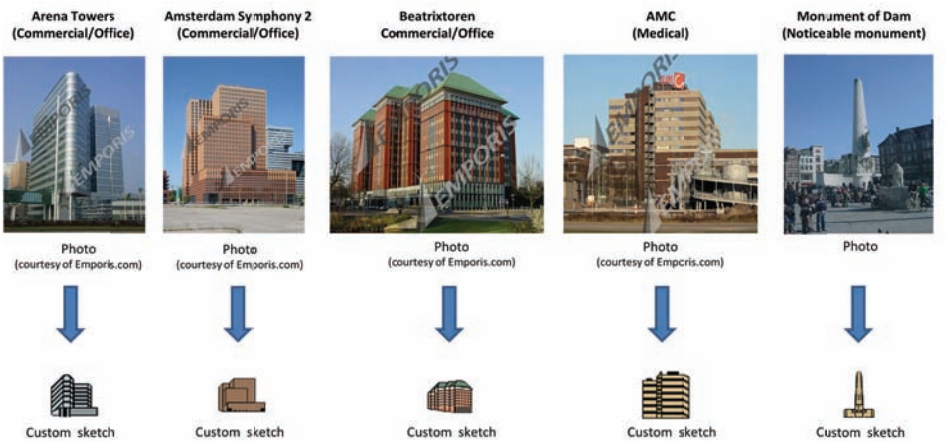


Figure 5.18: Examples of sketch landmark icons.

5.8 Global landmark visibility calculation

In Sections 5.4. and 5.5 the importance of a landmark visibility indication on the mobile map was explained. To calculate this visibility, a software framework is required, which could determine whether a particular landmark is seen from successive positions in reality. These positions should be established at the eye-levels of a pedestrian from the ground (1.60m.) The framework would need a 2.5D or 3D model of the city of interest (greater than the actual city centre) in order to compute this information and produce a visibility map layer for each of the selected global landmarks. This framework was offered by the University of Potsdam, in a research cooperation in the framework of this PhD project. A 2.5D map of Amsterdam was kindly provided by the municipality of Amsterdam as restricted data in the form of ESRI shape files to be used solely for the aims of this research. The geographic area that this map covered is shown with a red outline in Figure 5.19.

Figure 5.19: The area of Amsterdam for which the visibility of global landmarks was calculated [4.76551E, 4.96949E] x [52.28037N, 52.40711N].

The selection of global landmarks falling inside the above area for visibility calculation was made based on their heights. Any object or building with a height equal to or above 30m was defined as global landmark. The height was provided by the 2.5D shape files, but sometimes the values were not correct, due to inaccuracies of the data provided. The reason for these inaccuracies was the method used for creating the elevation Z-values for the buildings of Amsterdam, by combining a 2D topographical base map of Amsterdam with AHN (digital elevation map of the Netherlands) data. When these two layers were overlaid, the height points which fall within the limits of a building could be determined. To compensate for inaccuracies in the x, y values of the AHN data, the building limits were shifted 50 cm towards the inner side. Following that, the average height (Z) of all points that fall within the building limits were calculated. However, differences between heights within the limit of particular buildings were still produced due to particular structural elements of the buildings, such as chimneys and pointed roofs. Furthermore, possible positioning errors and the fact that the 2D data was from 2006 and the AHN data from 1997 and 2003 could have further contributed to the generation of height inaccuracies. To cope with these errors, an additional verification and correction was done, using the height data of (3D) buildings of Amsterdam, as provided by Google Earth. The global landmarks were then categorized based on the types as distinguished in Figure 5.16.

The dimensions of the resulting visibility layers were 1536x1536 pixels and referred to the exact geographic area, as shown in figure 5.19. The format was greyscale raster PNG where the amount of visibility was indicated by grey tones. For instance, areas on the layer where the landmark is totally invisible are black and the opposite stands for the white areas. The intermediate grey tones indicate areas where the landmark is partly visible. An example of a visibility layer of an actual global landmark in Amsterdam, the Okura Hotel, is shown in Figure 5.20.

The visibility layers could be directly utilized by the interface in order to provide an indication of the visibility of landmarks that appear on the mobile map, by projecting the position of the user in reality onto those layers. Each pixel of the visibility layers refers to particular geographic coordinates, which have a particular grey tone value. If that value is below a predetermined threshold, say 128 out of 256, the landmark should be regarded as invisible and if it is above that threshold, as visible. Values above 50% of the visibility scale show that at least one of the borderlines of a particular landmark is already marginally visible through other obstructing buildings or objects and its view can be further uncovered with slight movements of the observer. Besides that, the amount of processing power needed for calculating the visibility of many global landmarks using greyscale visibility layers is huge for a mobile device. By selecting a threshold value in the 50% of the scale from visible to invisible it makes it possible to convert the layers into black & white format which can be processed much faster. Using this information of binary type (visible=1, invisible=0), the appearance of global landmarks could be adapted on the map accordingly.

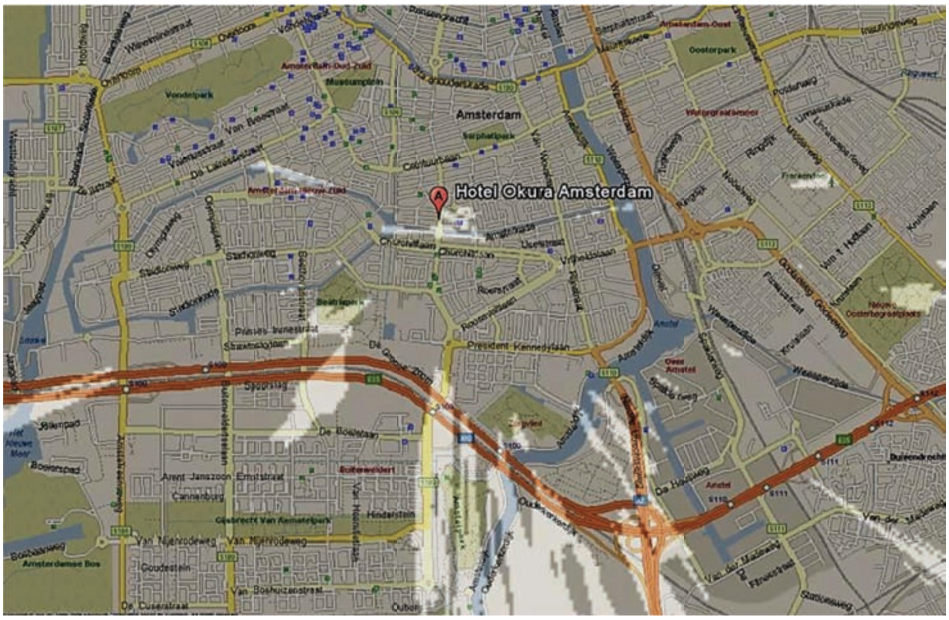


Figure 5.20: Example of a landmark visibility layer (Okura Hotel, Amsterdam, 78 metres high).

5.9 Prototype development environment

As it comes to prototype development, there are many different approaches. It may range up from simple paper mock-ups to fully interactive, working prototypes, and it can include intermediate, progressive steps from very simple to very advanced forms of design. Many examples of this diversity can be found in Section 3.3. In this research, given the resources available, it was decided to follow a rapid prototype development by employing direct code writing based on the proposed conceptual design and the related information requirements. By doing so, more time was available to build a fully working interface, eliminating minor functionalities whenever implementation would really become problematic. Such minor functionalities could then be replaced by simulations (not visible to the user) that would work in such a way that they would not affect the interactivity and overall performance of the prototype. Context of use is one of the most, if not the most important factor of usability, and having a design solution that could be evaluated in the real context of use that it was designed for, is the most direct and accurate means to test its usability.

In order to select a development environment for the prototype, the specifications of the mobile device platform that could accommodate the proposed technical design solutions should be set. Still following the UCD approach, the minimum hardware and software requirements of the mobile device on which the prototype should run are:

1. The mobile device should be small enough to fit in the palm of a hand, as the majority of currently used mobile phones does. At the same time, it should accommodate a screen large enough to be clearly seen by the average user, provided that any vision problems of the users are already addressed. The screen should also be readable under strong sunlight conditions without significant problems. The use of special design solutions in this research, as for example the reverse overview+detail option, requires a minimum screen size of 3.2 inch and a resolution of 320x480 pixels.
2. The mobile device should integrate location (a GPS receiver) and orientation (electronic magnetic compass) sensors. The inclusion of an electronic acceleration sensor (accelerometer) would be convenient as an automatic map rotation change based on the user's state of movement could then be examined.
3. The mobile device should integrate a digital camera in order to examine the possibility of automatic visual landmark recognition.
4. The mobile device should be able to run Google Maps and third-party applications (as the prototype to be developed) based on Google Maps API easily.
5. The mobile device should be able to connect to the internet wirelessly through mobile networks ubiquitously accessible, such as GPRS (GSM) or 3G in order to gather Google base maps and related geographic information.
6. The mobile device should be available to the researcher.
7. The mobile device should have a data processing speed which is enough for executing demanding functions of the prototype interface, such as continuous map rotation and overview+detail (dual) map, flawlessly and smoothly. Previous empirical experience suggests that the CPU frequency of the mobile device should be at least 500 MHz in order to accommodate those needs conveniently. The device should also provide an amount of available RAM memory for executing prototype applications with large datasets. These data include the landmark visibility layers, landmark icons, text information and multi-perspective photos of landmarks, The estimated data volume is 16-24 Mbytes.

8. The mobile device should have a touch screen. Without that it would be very difficult to select particular landmarks on the map, in order to get additional information, or to pan the map amongst other things.

To address these requirements, the mobile device may a smartphone, which is nowadays the successor of both PDAs and mobile phones. Although there are currently several different smartphone platforms such as Apple iPhone, Google Android, RIM Blackberry, Symbian and Windows Mobile, a Google Android smartphone was selected for the following reasons:

Google Android is an Open Source, Java-based platform, contrary to e.g. iPhone and Windows Mobile. Java is a programming language that the researcher has a fair knowledge of. Open Source software makes it easier to cooperate with other programmers and exchange ideas as there are no strict copyright restrictions for code distribution. Thus parts of code that provide particular interface functionality could be gathered from online sources and used for free. This reduces the time needed for prototype development, as basic interface functionality can be achieved relatively fast, by adapting existing code to the design requirements set by this research. A large Android programming community exists and Google offers an extended software framework with often updates. As an IDE (Interface Development Environment), Open Source Eclipse Classic v3.6.1 software is well integrated with the Google Android Software Development Kit (SDK), which is free. Combined with Android Development tools (ADT) plugin, Android Framework API and the standard Java Development Kit (JDK), Eclipse offers a powerful environment for creating Android applications. With the use of it, it is also very easy to install and run new applications in Android and perform debugging during software implementation.

Google Android is a multi-sensory platform, integrating many different sensors (GPS, accelerometer, compass, light, proximity) as part of the standard device architecture. An Android-based smartphone that addresses the eight requirements listed above was the HTC Hero, which was used as the hardware basis for the software implementation of the prototype.

5.10 Code development and issues

Following the conceptual design of a mobile navigation interface and the proposed technical solutions making use of UML sequence diagrams, a prototype was implemented in the form of a Java Android application. During that development, many different issues had to be addressed and the selection of the best solution amongst alternative ones was not always easy. A sequence of steps involving the materialization of different parts of the interface will be presented in this section, explaining the reasons behind following particular design directions.

5.10.1 LandNavin prototype (LN)

Starting with the implementation of a mobile navigation interface for Android using Google Maps, it was decided to provide with it a single name which at the same time would reflect the basic idea behind it. "LandNavin" (after Landmark-based Navigation interface) as a prototype name met that purpose and was used throughout the development and testing process. From now on, for simplicity and space-saving purposes, LandNavin will be referred to as "LN".

5.10.2 Map orientation issues

The first step in the development of LN was to create a simple North-up map which can be zoomed and panned. The map should also show the user's position which should be updated regularly as the user moves. This could easily be built, using freely available code by Google. Transforming the map into a rotating one, using the electronic compass heading data, was however much more complicated. Google API did not provide direct map rotation support, so the function had to be developed using a complicated trick of rotating the display that contained the map rather than the map itself. That led to many problems, such as a wrong panning direction when the mobile map was not facing the North, difficulties with drawing the landmarks on the map and rotating them together with the map without losing their correct geo-reference. A source of the problem was that it was decided to keep the landmark icons always up while the map is rotating, to make it easier for the user to recognize them. That problem was finally solved by carefully using pre- and post-rotation of the map and the landmarks on it, in order to always align the references of all the icons on the map with their new position and orientation.

After successfully implementing a heading-up map, it was noticed that the map was instable, as it was rotating with very slight movements of the user, making it practically difficult to read. That problem was solved by putting a threshold of 3 degrees and using a calculation of intermediate values between successive compass bearing values playback of them, using a delay function. In this way the rotation of the map was smoothed out.

The position of the user on a North-up and a heading-up map was a next decision point. As North-up maps are used for getting an overview conception of places and what is existing around, the position of the user was set in the centre of the map (vertically and horizontally). A heading-up map, on the other hand, continuously provides a view of what exists in front of the user, which has more importance than what lies behind him or her when moving forward. However, the user still needs to have a general idea of what is around him or her in order to keep his or her orientation. To compromise between the North-up and the heading-up information needs, the position of the user was set to 1/3 vertically starting from the bottom of the map and in the centre of the map horizontally.

To make the map orientation mode obvious to the user, and manually changeable, an on-screen button had to be added that allows for direct access to this fundamental function. The state of the button should be clearly indicated all the time so that the user is not confused. There are examples of software interfaces, particularly mobile navigation interfaces, where the buttons change their labels every time they are pressed. The problem is that the user is not sure whether the button will perform what is written on the label (e.g. 2D) when it is pressed, or whether the label shows the current state (e.g. 2D) which will change (to e.g. 3D) if it is pressed. For that reason, the solution used here was a toggle button with a permanent label referring to North-up (N). The button colour becomes green when pressed; indicating that in this case the North-up map is enabled. Otherwise the button becomes grey, showing that the map is not North-up anymore, but heading-up.

Changing the map from North-up to heading-up and vice-versa immediately does not let the user align his or her mental map with the new view and this can produce confusion. Animations are more usable when changing zoom levels, and / or panning a map (Midtbø & Nordvik, 2007). Changing the map orientation can be regarded as a type of panning, as map contents move to a different position, not by following a straight line but an arc. Therefore, to cope with this issue, the same solution for reducing the heading-up map sensitivity to user movements was applied here as well. Intermediate values between the compass bearing values are calculated (i.e. between a heading-up map bearing value (0-360 degrees) and 0 degrees of the North-up map and played back in a delayed manner. This smoothes-out the transition / rotation between the two map orientations.

Following the suggestions from the requirement analysis stage, the solution of automatic change of the map rotation from North-up (during initial orientation) to heading-up using the accelerometer of the mobile device was put to test. Although there was a lot of experimentation with different movement threshold values and data filtering techniques, the function could not produce acceptable results. Instead, it would change the orientation of the map randomly, something that would add more confusion to the user than convenience. Therefore, this approach was withdrawn totally and only manual change of map orientation through the on-screen button is allowed.

As an additional orientation support tool and indicator of the map's orientation, and in line with the requirement analysis findings, a small compass was put in the right hand top corner of the mobile interface. The compass always shows the direction of the North when a heading-up map is used and it is locked to the North-up position when the North-up map is used.

Changing the map to satellite view was another function that was included. To make it directly accessible, a new on-screen button was added, again changing colour from grey to green when enabled.

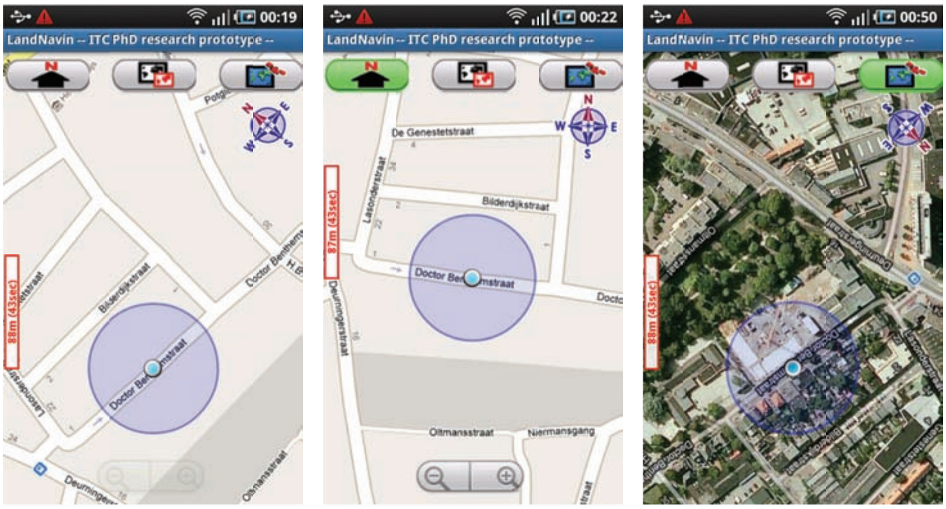


Figure 5.21: The basic prototype interface: a heading-up map is shown on the left and a North-up on the right. A satellite heading-up view enabled.

Three screenshots of the basic prototype interface including the on-screen buttons, the compass and the scale bar are shown in Figure 5.21. The map is in heading-up mode in the first screenshot and the zoom buttons are semi-transparent as the user has not tapped anywhere on the screen of the mobile device for a few seconds. In the second screenshot, the North-up map is enabled, something that can be identified from the green colour of the "N" button on the upper left corner of the screen. The zoom controls are now visible, as the mobile device display has just been touched. The purple circle around the user's position which is shown in light blue colour represents the accuracy of the GPS positioning. And finally, in the third screenshot, a heading-up, satellite view is enabled as the green colour of the corresponding button on the right upper corner shows.

Looking at the two screenshots, the change of the GPS position on the map depending on which type of map is used but also the movement of the scale bar following the position circle are observed.

5.10.3 Map controls

Mobile device screens are small and the use of space on them should be very carefully considered. Anything that takes space from the mobile map should only be there if it is needed. On-screen buttons and tools sacrifice the map's visibility, thus the use of semi-transparent compass, scale bar and on-screen buttons helped reducing that problem. Besides, button transparency change was added, which makes the buttons gradually becoming more transparent when they are not pressed for a predetermined time interval (5 seconds).

To enable the reverse overview+detail (dual) map, a new on-screen button was placed on the top centre of the display, sharing the same properties as the North-up / heading-up button (semi-transparency, gradually becoming more transparent when not used and green colouring when enabled). An illustration of how the dual map actually appears on the interface is shown in Figure 5.22. The (red) destination arrow is also shown, continuously pointing in a straight line at the currently selected destination.

Figure 5.22: Actual appearance of the dual map on the interface.

To avoid placing another separate button with which the user could force the map to centre on his or her current position after applying a lot of panning, an automatic return to current position after 10 seconds was enabled. As long as the user is panning the map, the map stays where the user moved it to. If there is no action from the user's side for 10 seconds, the map is returning to the current (GPS) position. If the map is heading-up, map rotation also stops for the same amount of time. This was set for practical reasons, as if the map rotation was on during panning, the rotation centre would be different than the centre of the map after panning to a different position, which could create confusion to the user. The 10 seconds delay can be ruled out by pressing two times the North-up button. In this case the map directly centres to the current position and the rotation starts immediately if it was enabled before the panning was performed.

5.10.4 Software crashes

Interface exception errors appeared many times while testing preliminary versions of the mobile navigation interface. For example, when zooming in and out was performed while the map was auto-panning to current position and the GPS signal was not good enough to get a position fix, the interface would stop working. Placing software protections in various parts of the code helped eliminating these errors, by not allowing conditionally unacceptable processes to run.

Another source of errors was the maximum application memory heap available for Android (until version 2.1), which was 16MB. Version 2.2, which is the latest and offers a much bigger memory heap, was not yet available for installation in the mobile device at the time of the interface implementation. To increase the amount of free memory and thus the processing speed of the device, the amount of landmark visibility layers was reduced to only the ones referring to landmarks which would be visible from at least one point along the route that the user would follow.

The interface was crashing also many times when the dual map was used, due to low memory issues. This happened because Google Maps required downloading of two different map tile sets sharing the same memory limitation as they belonged to the same application. That problem was solved by two separate classes for the main application (LN) and the detail map view, so that each of them can use 16MB of memory.

5.10.5 Landmark handling

As both local and global landmarks should be shown in the mobile interface and they should be differentiated, a dotted circle was put around the global landmarks to provide an additional reference to them, directly recognizable by the users. But this circle had also another important function: to inform the users about the visibility of global landmarks from current position through a change of colour (blue: visible and red: invisible). This solution is in line with the recommendations of the requirement analysis stage. Before that, different solutions were investigated, as, for example, changing the transparency of the global landmarks depending on their visibility (opaque when visible and semi-transparent when not visible). However, these proved to be inferior, as the change of transparency of the landmark icons is almost unnoticeable under sunlight conditions.

Interface response when the user enters an area outside the landmark visibility layers coverage was also considered when implementing the interface. Although this would not happen anywhere near the test areas, it was regarded as an issue which could appear if visibility layers with different area coverage would be used later on. Since the visibility of global landmarks cannot be computed outside the layer areas, it was decided that they should be treated as local landmarks, thus their visibility property will depend on other factors such as the user's position, bearing and distance from the landmark. An example of a global landmark with the visibility circle around it is shown in Figure 5.23. As the circle around the landmark is blue, it is expected that that the landmark is visible from the current position of the user.

Figure 5.23: A global landmark (Church Oudekerk), shown as visible from the current position.

Multi-perspective landmark photo provision based on the user's bearing towards the landmark was another design consideration during the requirement analysis stage. However, it would be difficult to implement that solution by showing photos of each of the sides of a landmark (usually 4 for buildings). As the side walls of the buildings are not always perpendicular to the cardinal points, additional orientation information would be needed for each landmark-building in order to calculate which side is visible from a particular position of the user. Besides that, there are also landmarks which do not have square or rectangular but e.g. triangular or round footprints. Thus a simpler solution was to collect 4 photos for each landmark, taken from its North, South, East and West perspectives. By giving to these photos file names related to the landmark name and the perspective they show, the interface could select and present them in a fast and easy manner. For example, the East perspective photo of Vrije Universiteit Amsterdam was named as *Vrije Universiteit_e.jpg*, and its South perspective photo as *Vrije Universiteit_s.jpg*, allowing the interface to calculate which of the views fits better to the bearing of the user towards that landmark. In case there are less than 4 photos of the landmark available, one of them has to be named without the bearing point letter at the end, so that the interface can use that one for all the remaining views. An example of a landmark pop-up photo selected out of four available based on the position of the user is shown in Figure 5.24.

Figure 5.24: One of the four available photos of the landmark "Monument of Dam" selected based on the user's position and shown in a pop-up window.

As it comes to the resolution of the landmark visibility layers (1536x1536 pixels), the amount of memory needed for each of them was higher than expected. To reduce that inconvenience, their resolution was reduced to 512x512 pixels. This reduction theoretically affected the landmark visibility calculation accuracy, but the user would still be able to evaluate the functionality without critical problems. To reduce the complexity of the landmark visibility calculations, the grey scale layers were converted to black & white ones, where the visibility is either on or off for each pixel. Georeferencing was also applied to them through ILWIS software (URL31) to make the handling of the layers easier.

An additional issue that was found during the preliminary tests of the interface was that GPS accuracy also affected the landmark visibility calculations. For instance, when the GPS shows the user's position 5-10 meters off his or her actual one, a visible landmark can appear invisible while it is not or vice versa. An experimental solution to that problem was the addition of a one-pixel buffer to the geo-referenced visibility layers (1 pixel corresponds to around 7 meters in reality).

To show additional landmark information, a small database with text and photos for each of them was created. By clicking on each landmark, the user is provided with a pop-up window showing any available information for that landmark.

5.10.6 Multi-path provision

To provide the user with multi-path routing to the destination(s), was something that could be done automatically. For example, when the user is selecting a particular destination, the interface could calculate the multi-paths based on the user's profile information (time availability) and a set of pre-determined routing parameters. However, that proved to be impossible with the current version of Google Maps API, as it does not allow for the creation of more than one route to a destination. There are ways to bypass that limitation, but still the routes will be automatically calculated by Google, preventing us from controlling the parameters of the routing. To address that issue, the solution of superimposing multi-paths in the form of multiple lines created on Google Earth was selected. These multi-lines provided a result different than the "flow channel" idea which could be recreated using multi-polygons, but the interface was getting very slow in response when that was tried. In any case, the multi-line solution was still a valuable way to demonstrate the users the multi-path idea and evaluate its usability during the usability testing part of this research.

To construct the pre-made multi-paths, the starting and destination points that would be used for the usability testing of the interface had to be selected already in this stage. In total 4 destinations, 2 for each of two test areas, were selected. The first area was around the centre of Amsterdam, with a starting point at Dam Square and the two destinations are the Bijbels Museum and the Doelenzaal music theatre. The second area was outside Amsterdam city centre, with a starting point at Wibautstraat Metro Station and the two destinations being an Albert Heijn supermarket at Krugerplein square and Café Dauphine near Amstel Station. These areas have the same starting points with the ones used for the requirement analysis experiment (see Section 4.8.3), but the destinations are different. This modification was done in order to better adjust the time needed for covering the distances between each starting point and destination. In particular, the average time needed to go from the starting point to the first destination and from the first destination to the second one should be the same. By doing so, the performance of the TPs in each route during the usability testing phase would directly comparable.

The first set of multi-paths for each area was created for little time availability, including the shortest path to destinations and a few alternative short paths. The second set was created for plenty of time availability, including the shortest path to the destinations and several alternative paths, falling inside a circle that had the starting point and the destination as points on the opposite sides of the circle. Eight sets of local landmarks to be shown were also made, one set for each multi-path. In Figure 5.25 the software menu for destination selection and an example of multi-paths for plenty of time available are illustrated. The destination shown with a green flag is destination no. 2 (Doelenzaal Musical Theatre) in Amsterdam centre test area. Several local landmarks along the paths to the destination can be recognized in the example.

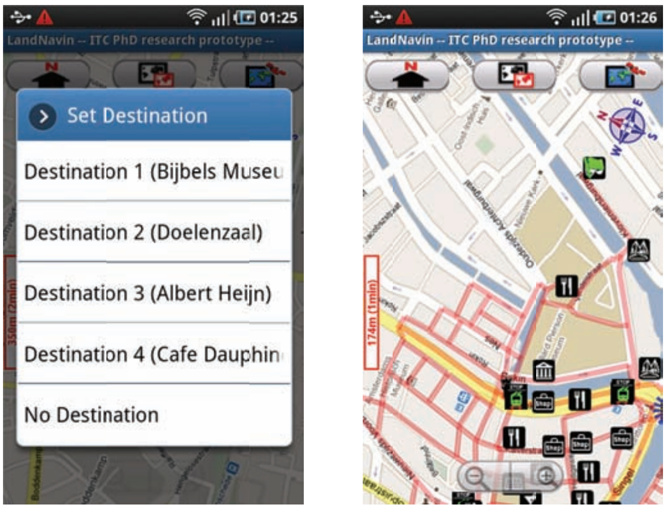


Figure 5.25: On the left: destination selection menu and on the right: multi-paths towards a Destination no. 2 (Doelenzaal Musical Theatre).

5.11 Conclusions

Designing a usable mobile navigation interface requires an extensive investigation of the specific use and user contexts involved and a careful modelling of the user questions, problems, interactions and tasks. Using scenario-based task and use case analysis, the foundation for developing such an interface was set and relevant design guidelines were deployed. UML was helpful for transferring the conceptual model of the system into a prototype by recreating visual, high-level models of the configuration and functionalities of the system. Using these models, a prototype mobile navigation interface was developed and the issues that had to be addressed during its implementation were presented. The proposed interface is expected to help users orient themselves and navigate easily, supporting at the same time the development and use of their mental maps in order to get familiar with new urban places faster. Evaluating the implemented prototype with real users in real contexts of use in order to assess its usability will be the subject of Chapter 6.

6. Usability evaluation - directions for design improvement

6.1 Introduction

After completing the development of LN prototype, an evaluation of the design as part of the conducted UCD methodology was planned. The aim of that evaluation, in the form of an empirical, field-based user testing, was to assess the usability of the prototype interface. In this way, the applied technical solutions would be evaluated and the extent to which the user requirements were met would be investigated. Usability testing unveils the parts of the implementation which would need to be reformed and improved and helps formulating prototype optimization guidelines. Following those, the usability of the prototype for the given context of use and group of end users can be further enhanced. This chapter elaborates the usability testing of LN, through a description of the aims of this evaluation, the applied testing methodology and the execution of the experiment in Section 6.2, an analysis of the experimental findings in Section 6.3 and an extensive discussion of the results in Section 6.4.

6.2 Evaluation aims, methodology and execution

Conducting a usability testing as part of UCD is the evaluation of a developed prototype through empirical or inspection-based methodologies. Empirical testing involves users much more than usability inspection which is generally confided to experts and project members. The aim of the testing is to identify possible usability problems and gather information regarding the performance of the test persons. Thus, measuring the time spent to complete tasks, the success and error rates on doing that and the satisfaction of using the prototype is a key element. To do so, a combination of objective (performance) and subjective (preference) metrics should be applied.

Central to this research are the links between reality, the abstract representations of that reality in the form of maps and the users' mental maps. Doing the usability testing in the lab would exclude some of these links as the real context of use would not be considered properly, something already discussed in Section 4.6. A field-based testing would be more convenient in these terms, especially if content and presentation issues of the prototype could also be investigated in real usage conditions without the need for an additional laboratory testing. One of the main problems of field-based testing, the high-resource demand, has already been successfully addressed during the requirement analysis experiment of this research by using special technical solutions (see Section 4.8.6).

The aims of the test and the roles of the test persons (TPs) involved should be clear and described into decent detail to the participants. It is important that the TPs do not feel that they are the objects of the test and that their abilities and capabilities are under inspection. It should be clear to them that it is the prototype that needs to be evaluated and that they offer a great help in directly and indirectly identifying any positive and negative aspects that have to be considered by the developer for improvement.

6.2.1 Usability questions

Before outlining the questions that the usability testing of the LN prototype intends to answer, it is important to remember what the initial goal of its development was. This is: helping pedestrian visitors to orient themselves and navigate in unfamiliar cities or city areas through a usable mobile interface. Based on the conceptual design following the requirement analysis stage of this research, personal geo-identification (orientation) and navigation was broken down into four main tasks. Those are Initial Geo-identification, Identification of Destination and Travel Decision, Route Confirmation / Route Control / Reorientation, and Destination Confirmation (see Section 5.2). Each of those tasks embodies different questions that the users of a mobile navigation system are asking, and technical solutions to help answering those questions were proposed. During the (prototype) design evaluation stage of UCD, the usability of these solutions has to be assessed by providing the users with real tasks in which the formulated questions should arise. Examples of those questions are: "Where am I?"; "Where is my destination?"; "Am I following the correct route?"; "Is this the correct destination?" and so on. To do so, task scenarios had to be created where the user should find answers to those questions in order to complete the tasks using the available tools and information offered by the prototype.

In line with the general research questions of this research and the user task questions, specific questions regarding the functionality of the prototype interface when it is used as a supporting tool for orientation and navigation were formulated. These questions to be investigated in the usability testing procedure were divided according to the function that they were assessing in the following way:

1) Position of the user and map orientation:

a. Do the users easily and correctly understand their position on the map?

b. Do the users correctly understand their heading and direction of movement?

c. Is the use of a rotated map towards the heading of the users based on a digital compass useful and helpful for them in order to orient themselves and navigate, or do they prefer a static map?

d. Do the users use the North-up, the rotated map or a combination of them in order to carry out their tasks?

2) Reverse overview+detail map

a. Does the use of the reverse overview+detail map reduce the need for continuous zooming-in / zooming-out by the users or not?

b. Does the use of the reverse overview+detail map help users geo-identify themselves correctly and relate reality to the mobile map with easiness or not?

c. Do the users easily understand the relation between the overview and the detail map (area, orientation) or not?

3) Multi-path and time availability

a. Do the users find multi-paths and free navigation better than following a single route or not?

b. Is it easy for the users to find their way using multiple paths combined with landmark information or not?

c. Do the users like the idea of multi-path routing alteration based on their time availability or not?

d. Do the users like the appearance (colour / shape) of multi-paths on the map or do they prefer another way of displaying the same information?

4) Landmark visibility

a. Do the users find global landmark visibility information useful for orientation and navigation or not?

b. Is the landmark visibility information accurate enough to let them relate what they see in the surroundings to what they see on the mobile map correctly?

c. Is the landmark visibility indication easily and correctly perceived by the users or do they prefer another solution for being shown that information?

5) Landmark pop-up information

a. Do the users make use of the pop-up landmark information (photos + description text) and find it helpful to carry out their tasks successfully or not?

b. Would the users prefer an alternative way of being shown that or additional / different types of information?

c. Do the users find the use of multiple-perspective photo selection based on their location and orientation better than single landmark photos or not?

6) Landmark symbology

a. Do the users easily understand the meaning of landmark symbols and icons / sketches or not?

b. Do the users like the size and scaling of landmark icons / symbols / sketches in different zoom levels of the map or not?

7) Scale bar and on-map compass

a. Do the users find the movement of the scale bar position (starting from the user's position) and its vertical orientation more useful than a standard fixed-position horizontal scale bar?

b. Do the users like the combination of distance and time needed in the scale bar or not? – Do they make use of that combined information during the tasks?

c. Do the users like the rotating compass and do they make use of it in order to orient themselves and navigate?

8) Interface interactivity

a. Do the users easily understand the meaning of the on-screen buttons, their functions and their state (enabled / disabled) or not?

b. Is the response of the interface fast and convenient to the user input (taps on the map for landmark information retrieval, zooming-in and out / panning / button press response) or not?

9) Landmark filtering

a. Is the filtering of landmarks on the mobile map based on the heading of the users and their selected destination helping them to orient themselves and navigate with more ease? Does this reduce their mental load or do they prefer having all the landmarks visible on the map at the same time at any instance?

b. Do the users like that the function of landmark filtering is off when North-up map view is enabled and on when the rotated map view is enabled or not?

10) General impressions, problems and areas for improvement

a. Do the users find LN in general more usable than existing applications that they have tried (e.g. Google Maps)?

b. What are the problems that the users are confronted with during the use of LN reducing their orientation and navigation performance?

c. What are the functions that could be improved in LN so that it meets their needs and expectations better?

d. Do the users get satisfaction from the use of LN and would they use it for future travels if it was possible to have coverage of their city of interest?

6.2.2 Task scenarios

Navigating from a starting point to an unfamiliar destination was the basis of each user test session incorporating the task scenarios that were developed. The scenarios had to reflect as much as possible real use and user contexts when there is a need for an electronic navigation tool. It was considered to be useful to compare the user's performance and answering of the main task questions using another existing application interface as well. By doing that, the usability of LN can be measured against a different implementation (of the same concept). In order to make the results of this comparison valuable for the aims of this research, both of the interfaces should share common characteristics as it comes to map style / colours / way of performing basic functions like zooming-in / out, and so on. In this way the possibility to get different results based on aspects other than the functionalities and available information on each of them is reduced. Considering the fact that LN was implemented using the Google Maps API, Google Mobile Maps software (from now on referred to as GM) is the best selection for this comparison. However, the user tasks should be slightly adjusted so that they do not refer to functions that are only available for LN.

The task scenarios were formulated as follows:

Task 1 - Initial Geo-identification

Scenario 1: *"You arrived at a certain place in a city and, as you are there for the first time, you try to understand where you are. You had a first contact (that lasted for half an hour) with the navigation interface earlier today when you tried to get familiar with its functions and capabilities. Now you try to orient yourself and understand where exactly you are and what is around you. You turn yourself around and observe the environment and the information presented on the map. Then you search for easily recognizable features in reality and on the map and you try to relate them. To help yourself further, you want to retrieve additional information regarding these features. You also search for important places for your trip such as transportation terminals that you should probably need later on. Then you try to estimate how far they are from you and in which direction. You try to find ways to ensure that your estimations are accurate so that you can move on in your trip without getting lost."*

Based on this first scenario, the following sub-tasks were created to assess the familiarity of the TPs with the interface basic functions and the support that LN can provide them to orient themselves and understand the surroundings:

a) Did you have enough time for familiarization with the interface or did you need more time?

b) Please look at the mobile map and then change its view from Northup to rotated, then from street to satellite and lastly from single to dual map. You can do that at any time during the experiment as desired.

c) Please select the rotated map type and then turn around yourself and observe the environment and the information presented on the map. Do you see any changes as you rotate?

d) Please look around you and to the mobile map and try to find any tall buildings, prominent landmarks or anything else that stands out from the environment nearby. Can you recognize any of these on the mobile map?

e) Please click on a few of the nearby global landmarks (with a ray-like circle around them) that appear on the map. Are the pop-up photos recognizable and of the correct viewing angle compared to reality?

f) Please try to find the closest train, bus, metro or tram station / stop. Estimate how far you are from it and in which direction it is.

g) Please select a global landmark that is not in the area around you and move towards that for 20 meters.

For GM, the sub-tasks were (re)formulated as follows (based on the same first scenario):

a) Did you have enough time for familiarization with the interface or did you need more time?

b) Please look at the mobile map and then change its view from street to satellite. You can do that at any time during the experiment as desired.

c) N/a for this task.

d) Please look around you and to the mobile map and try to find any tall buildings, prominent landmarks or anything else that stands out from the environment nearby. Can you recognize any of these on the mobile map?

e) Please click on a few of the nearby landmarks that appear on the map. Are the pop-up photos recognizable and of the correct viewing angle compared to reality?

f) Please try to find the closest train, bus, metro or tram station / stop. Estimate how far you are from it and in which direction it is.

g) Please select a global landmark that is not in the area around you and move towards that for 20 meters.

Task 2 - Identification of Destination and Travel Decision

Scenario 2: *"After orienting yourself and when you believe you can start navigating around the city, you want to select the destination that you want to go to. You have a particular amount of time available for that. You use the mobile interface in order to find your way to the destination and you observe if it takes into account your time available to show you proper route(s). Before you start moving, you try to make an estimation of how far the destination is and how long it will take you to reach it. You start moving towards the destination following the route(s) provided by the interface and you check whether your heading is correct by observing the mobile map and reality. You then try to locate a few landmarks along the path that you are following"*

The sub-tasks for LN are:

a) Please select the corresponding destination using the interface's "menu" hardware button and then the "destination" icon.

b) When the interface asks you to select time availability, please select first "plenty" and observe the routing that is created. Then select again the same destination but now with "little" time availability. Observe the routing again. Do you notice any differences?

c) Please select the destination again and now the time availability that is corresponding to your task. Observe the map and all the information provided and make an estimation of the distance of the destination from where you are, as well as the time needed to reach it.

d) Please click on the destination icon and observe the provided information. Is the destination description clear to you?

e) Please start moving towards the destination (in a straight line) for 20 meters and then stop and check the map. Were you moving in the correct direction?

f) Please observe the multi-path routing and the way it appears on the map. Make a rough selection of a path that looks best for you. Can you name three landmarks along that path?

g) Please navigate to the selected destination.

For GM, the sub-tasks were (re)formulated as follows:

a) Please select the corresponding destination from the available history list using the "menu" hardware button of the interface and then the "directions" icon.

b) N/a for this task.

c) Please make an estimation of the distance of the destination from where you are, as well as the time needed to reach it.

d) Please click on the destination icon and observe the provided information. Is the destination description clear to you?

e) Please start moving towards the destination (in a straight line) for 20 meters and then stop and check the map. Were you moving in the correct direction?

f) N/a for this task.

g) Please navigate to the selected destination.

Task 3 - Route Confirmation / Route control / Reorientation

Scenario 3: *"While you are moving for some time now towards the selected destination you want to check whether you are really following a correct route. You try to find two consecutive landmarks along the path that you are following and which are close to you so that you can check your route. You also try to find one global landmark towards the destination and find information about it. You want to see whether this landmark is visible from your current position so that it can help you orient yourself and if its visibility in reality is correctly indicated on the interface. Again you try to make an estimation of how far the destination is from your current position and how* *long more it should take you to reach it. Then you continue your way towards the destination while checking if your movement is in the correct direction on the map".*

The sub-tasks for LN are:

a) If you are not using the reverse overview+detail (dual) map, please do so. Confirm your path by naming one landmark along that and one global landmark towards your destination.

b) Now please estimate how far your destination is and how much time you need to reach it.

c) Please forget for a few moments about the multi-paths on the map and start moving for 20 meters directly along the line to the destination. Then stop and check the map. Were you moving in the correct direction?"

d) Please continue navigating to the selected destination.

For GM, the sub-tasks were (re)formulated as follows:

a) Please confirm your path by naming one landmark along that and one global landmark towards your destination.

b) Now please estimate how far your destination is and how much time you need to reach it.

c) Please start moving for 20 meters directly along the line to the destination. Then stop and check the map. Were you moving in the correct direction?"

d) Please continue navigating to the selected destination.

Task 4 – Destination Confirmation

Scenario 4: *"You are walking for some time now. When you reach your destination, please stop in front of it and observe it. Was that the correct one? Is it clearly recognizable on the mobile map?"*

The sub-tasks for both LN and GM are:

a) When you reach your destination, please stop in front of it and observe it. Is this the correct one? Is it clearly recognizable on the mobile map?"

b) Click on the destination icon and observe the provided information. Is the provided photo recognized and of a correct angle compared to reality?

6.2.3 Study areas and session structure

Most of the times, cities have areas with very different structural compositions. For example, the areas in the city centres are usually rich in, for example, noticeable monuments, churches and other landmarks while the areas away from the centre are not. This can make navigation easier (due to reduced structural complexity and more straight street lines) or more difficult (when landmarks are needed in order to orient, memorize a route and so on). To investigate the usability of the prototype in different city settings, two areas were selected for the tests. For each area two destinations were chosen, to be used interchangeably with LN and GM for the same TP, for comparison purposes. The areas were similar to the ones used for the requirement analysis stage experiment, presented in Section 4.8.3. The reasons for that decision were:

a) The landmark visibility calculations could only be done for Amsterdam due to the availability of data for 3D city modelling.
b) Travelling to Amsterdam with TPs proved to be a good practice from the previous experiment, as it allows for research introduction and briefing sessions to be done smoothly in the train just before the testing. At the same time, it helps the TPs embedding their role as travellers / visitors to an unfamiliar place.
c) Amsterdam is a very good example of a touristic city with a great structural diversity from the centre to the suburbs.

However, considering the observations of the previous experiment, new destinations were selected this time, more distinct and recognizable. In the earlier experiments, the destinations were sometimes hard to find, as for example Begijnhof, which did not have a well-indicated entrance.

For this experiment, the first area selected was again in the greater centre of Amsterdam, starting at the Monument on the Dam (S1) with selected destinations the Bijbels Museum (D1) and the Doelenzaal theatre (D2). The second was away from Amsterdam's centre, in a mostly residential and commercial area starting at Wibautstraat Metro Station (S2) as in the previous experiment. This time though, the selected destinations were Krugerplein (D3) and Amstel Metro Station (D4) (Figure 6.1).

As the prototype shows different multi-paths to the destinations associated by particular local landmarks depending on the two different time availabilities of the user, the performance of the TPs had to be tested with both of them. For practical reasons half of the TPs had to use the prototype with a multi-path created for users with plenty of time available and the other half with a multi-path created for little time available.

Each TP had to execute a session in one of the two Amsterdam areas, divided into two parts. First, starting from the predefined starting point he or she should navigate to the first destination using one of the two application interfaces (LN or GM). Second, starting from the reached destination he or she should navigate to the second one using the other application interface. The sequence of use of each interface should be reversed for each new TP in order to investigate the results of the "learning effect". This refers here to the influence of familiarity with a particular type of interface (e.g. GM) on the task execution performance with another, identical interface (e.g. LN).

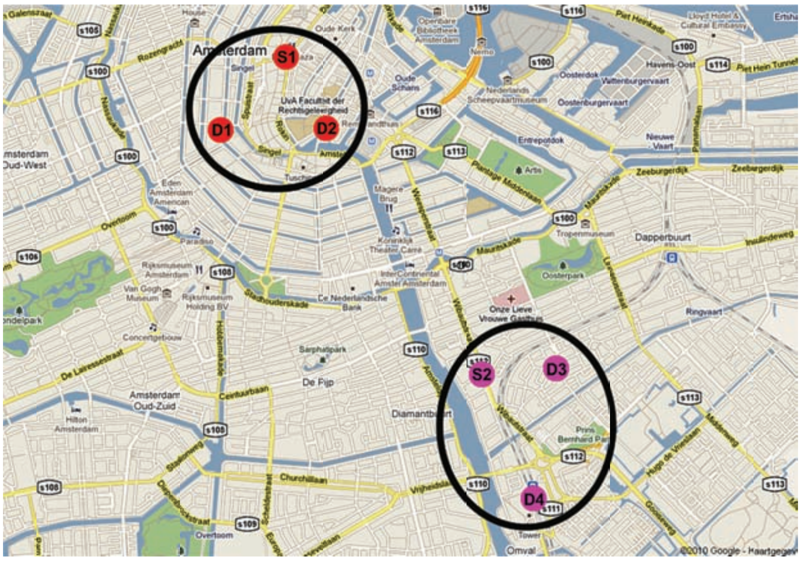


Figure 6.1: The two areas of Amsterdam selected for the usability testing.

The test parameters used to divide the TPs into groups for the experiment are two: the area of the test and the sequence of the interface used. Based on the two values each of these parameters can have, four groups (2x2) of participants could be constructed. Time availability is also considered as a test parameter but not for TP grouping, as GM does not offer different routing to the destination based on the available time of the user to compare with LN. It is still important, though, to assess the usability of this option and its effect on the TPs' performance during the analysis of the experimental results. As it comes to the number of participants needed for usability testing, (Nielsen, 1994) suggested that not more than five or six are needed and this number has also been verified mathematically by (Virzi, 1992). Considering the above, in this research the number of 6 participants in each of the four TP groups was regarded as suitable and feasible given the available resources. Therefore, in this case the total number of participants was 24 (2 areas x 2 interface sequences x 6 TPs). It is acknowledged that this number of TPs is too small to draw statistically strong conclusions, but enough to discover the main usability problems. The session structure for each TP is shown in Table 6.1, where the formation of the four TP groups is shown.

TEST	AREA	TIME	START	DEST.	INTERFACE	PARAMETERS	GROUP
TP1	CENTRE	P	S1	D1, D2	LN→GM	CPL	A
TP2	WIBAUTSTRAAT	P	S2	D3, D4	LN→GM	WPL	B
TP3	CENTRE	L	S1	D1, D2	LN→GM	CLL	A
TP4	WIBAUTSTRAAT	L	S2	D3, D4	LN→GM	WLL	B
TP5	CENTRE	P	S1	D1, D2	GM→LN	CPG	C
TP6	WIBAUTSTRAAT	P	S2	D3, D4	GM→LN	WPG	D
TP7	CENTRE	L	S1	D1, D2	GM→LN	CLG	C
TP8	WIBAUTSTRAAT	L	S2	D3, D4	GM→LN	WLG	D
TP9	CENTRE	P	S1	D1, D2	LN→GM	CPL	A
TP10	WIBAUTSTRAAT	P	S2	D3, D4	LN→GM	WPL	B
TP11	CENTRE	L	S1	D1, D2	LN→GM	CLL	A
TP12	WIBAUTSTRAAT	L	S2	D3, D4	LN→GM	WLL	B
TP13	CENTRE	P	S1	D1, D2	GM→LN	CPG	C
TP14	WIBAUTSTRAAT	P	S2	D3, D4	GM→LN	WPG	D
TP15	CENTRE	L	S1	D1, D2	GM→LN	CLG	C
TP16	WIBAUTSTRAAT	L	S2	D3, D4	GM→LN	WLG	D
TP17	CENTRE	P	S1	D1, D2	LN→GM	CPL	A
TP18	WIBAUTSTRAAT	P	S2	D3, D4	LN→GM	WPL	B
TP19	CENTRE	L	S1	D1, D2	LN→GM	CLL	A
TP20	WIBAUTSTRAAT	L	S2	D3, D4	LN→GM	WLL	B
TP21	CENTRE	P	S1	D1, D2	GM→LN	CPG	C
TP22	WIBAUTSTRAAT	P	S2	D3, D4	GM→LN	WPG	D
TP23	CENTRE	L	S1	D1, D2	GM→LN	CLG	C
TP24	WIBAUTSTRAAT	L	S2	D3, D4	GM→LN	WLG	D

Table 6.1: Structure of the test sessions for each of the TPs.

The colours in this table refer to the groups the TPs belong to: Group A is comprised of TPs tested in Amsterdam Centre area using LN interface first, Group B of TPs tested in Wibautstraat area using LN first, Group C of TPs tested in Amsterdam Centre area using GM first and Group D of TPs tested in Wibautstraat area using GM first.

Also, each combination of parameters that the TP test sessions should encompass is distinguished with a 3-letter code. In that code, C stands for (Amsterdam) Centre and W for Wibautstraat (first letter), P for Plenty and L for Little of time available (second letter) and lastly, L for LN and G for GM (third letter).

In order to execute the usability testing of LN, the TPs should represent the potential user of the interface. This user is a pedestrian visitor to an unfamiliar city / city area who uses a geo-mobile application in order to get information that could help him or her to orient and navigate. The age range of this type of user is very wide, composed by the age of any person who can use a mobile phone. However, for practical reasons, such as the safety of the participants and their legal responsibilities in case of an accident, in this research only adults above 18 years old were considered as prospective TPs.

The TPs could have different levels of knowledge and abilities regarding cartography, mobile maps and navigation systems, navigation and orientation techniques and educational level. The TPs who would be unfamiliar with both of the test areas could be scheduled for testing in any of those, and the ones who were familiar with one of the areas could be tested in the other one. In this way, any bias to the results due to previous experiences of the TPs would be avoided.

Although the real contexts of use are dynamic and even unpredictable up to some extent, a set of conditions had to be applied to the test sessions in order to limit the context diversity as much as possible. The test sessions had to be executed only during daytime (from 8:00 to 20:00 hrs. during the summer months in the Netherlands, when the tests were carried out). This limitation was necessary as the orientating and navigating performance is influenced by the amount of light available in the environment and LN is a prototype which was designed to be used under daylight. Using it at night would make it impossible for example to recognize many global landmarks, which, although they are in the visual range of the user, they cannot be easily seen or distinguished due the changes in their visual properties (e.g. colour). The weather conditions during the test had to be fair (cloudy or sunny days, with average temperature and wind speed) as in case of rain or very strong winds, problems could appear with the electronic equipment and the task execution process. Moreover, highly disturbing instances (demonstrations, national celebrations, road work and the like) in the test areas had to be avoided. These posed a threat to the TP's and researchers' safety but they could also negatively influence the task execution and the proper application of the research methodology described in the next section.

6.2.4 Research methodology

In order to select proper usability testing methods and techniques, first the goals of the evaluation experiment have to be defined. In case of LN, the users' reactions and interactions with the prototype need to be investigated. The performance of the users while carrying out should also be measured, and any possible feedback from the users that can help improving the interface further should be extracted.

It is particularly important to understand the users' feelings and mental processes behind their actions while using LN for orientation and navigation during the given tasks. For this aim, thinking aloud is a very useful method (see Section 4.8.4). Especially when the TP finds a problem or gets confused, thinking aloud allows for a deeper insight into the reasons behind these, through carefully targeted questions. The satisfaction of the TP from the use of the prototype and whether it meets his or her expectations can also be inspected through thinking aloud. This information should not only observed, but also captured and stored in a convenient medium so that it can be analysed later on for extraction of usable information and provision of possible (re-) development directions. Thus audio recording is always necessary when think aloud method is applied. However, this type of research material alone is very difficult to analyze and not complete, as it lacks information about the actual context of use, and the user actions and interactions which, in case of geo-mobile applications, are very important to understand (see Section 2.2.2). This problem can be solved by using video recording together with audio recording of the test sessions. Moreover, video-recording the TP from different view perspectives allow for more accurate analysis of the research data, especially when these different views are synchronized and contain time information. This, though, should not be done at the cost of TP's comfort.

As the usability evaluation methodology here copes with user interactions between the environment and mobile navigation interfaces (and also their mental maps), knowing the exact points in reality and on the mobile maps that the TPs are looking at would help analyzing their behaviour better. One of the hypotheses that immediately came into sight was that eye-tracking combined with thinking aloud would reveal much more information than each of these two techniques alone. The analysis of their combined results would allow for more concrete conclusions regarding both the reasoning and actual behavioural patterns of the TPs.

The only way to test whether eye-tracking could actually meet those expectations was to obtain a mobile eye-tracking system that could be used in the field alone and in combination with thinking aloud. The system had to be mobile, as the configuration of stationary eye-tracking systems does not allow for outdoor use and demands limited movement of the TP's head in order to produce accurate data. Besides that, the stationary systems can be calibrated only for tracking close objects (e.g. a computer display or a mobile device screen) and not distant ones (e.g. landmarks in a city). Instead, mobile eye-tracking systems use sensors attached on glasses that the TP wears so that he or she can move freely. Their calibration can be for both close and distant object tracking.

To test the possibility of integrating a mobile eye-tracking in the usability testing methodology for LN, an ASL Mobile Eye system was obtained, kindly provided by UCL (University College London). This was then used in a research experiment of an ITC MSc student, investigating the usability of eye-tracking in geo-information processing and dissemination (Razeghi, 2010). Working together with her on setting up the environment for the tests and calibrating the ASL Mobile Eye system, it was proved to be impossible to calibrate the system for tracking both distant and close objects. Besides that, the viewing range of the scene camera, although it was the largest available, was still too small to cover the whole point of view of the experiment. Thus, depending on the vertical angle adjustment of the camera, either the mobile device display or the scene in front of the user was out of view (Razeghi, 2010). A synchronised recording of the resulting eye-tracking together with other video sources in the field was also practically impossible with at least the ASL Mobile Eye system, as all the gaze data analysis had to be done afterwards on a desktop or laptop computer.

Considering the above findings it can be stated that the usability of current mobile eye-tracking systems in the context of user research on mobile navigation systems is low. The complexity of calibrating and using such a system and the identified problems suggested that it should not be not be part of the testing methodology of this research.

Although the idea of using a mobile eye-tracking system was finally abandoned, the earlier discussed combination of field-based usability testing methods and techniques including mainly observation, think aloud and synchronized video / audio recording was already a very convenient approach.

A technical system that supports synchronized multiple video and audio data collection has already been implemented in the requirement analysis part of this research (see Section 4.8.6). An improved version of that field-based remote observation / recording system was developed to be used for the execution of the usability testing of the prototype of LN.

The parts that were improved compared to the previous version of the system were the video transmitter / receiver sets, the camera lens and the video / audio recorder. In detail, the video transmitters were replaced with new ones that could use 15 different channels and produce an output power of 700mW (compared to 200mW of the previous ones). The video receivers were replaced accordingly to accommodate 15 channels. The result of this upgrade is less interference between the two sets, as the frequency difference between the highest / lowest channels is now 288MHz (compared to less than 100MHz before). The increased transmitting power also increases the range and quality of the observed / recorded video.

Two out of three camera lenses were also replaced with ultra-wide-angle ones, as it was always difficult in the past to adjust the hat of the TP in a way that his or her hands holding the mobile device would always be inside the point of view of the lower hat camera (Cam 2 in Figure 6.2). Besides that, with the old system the researcher had to walk carefully and not move around so much in order to have the TP always inside the point of view his camera (Cam 3). Both of these issues were addressed with the use of the new lenses which are ultra-wide (170 degrees POV).

The mobile video recorder was replaced as well with a much smaller (in size and weight) unit which records on Compact Flash cards with higher resolution video (720x575 pixels). Its lower weight and size increases the comfort of the TPs while at the same time it provides higher immunity to noise and vibration due to the solid-state nature of the recording medium. It also integrates a GPS receiver with on-screen displaying of coordinates and a lap timer that can be used to measure the time of each individual session. The video recorder provides power to the two cameras and the video transmitters / receiver as well, further reducing the power cabling complexity of the observation system. A diagram of the new system is provided in Figure 6.2.

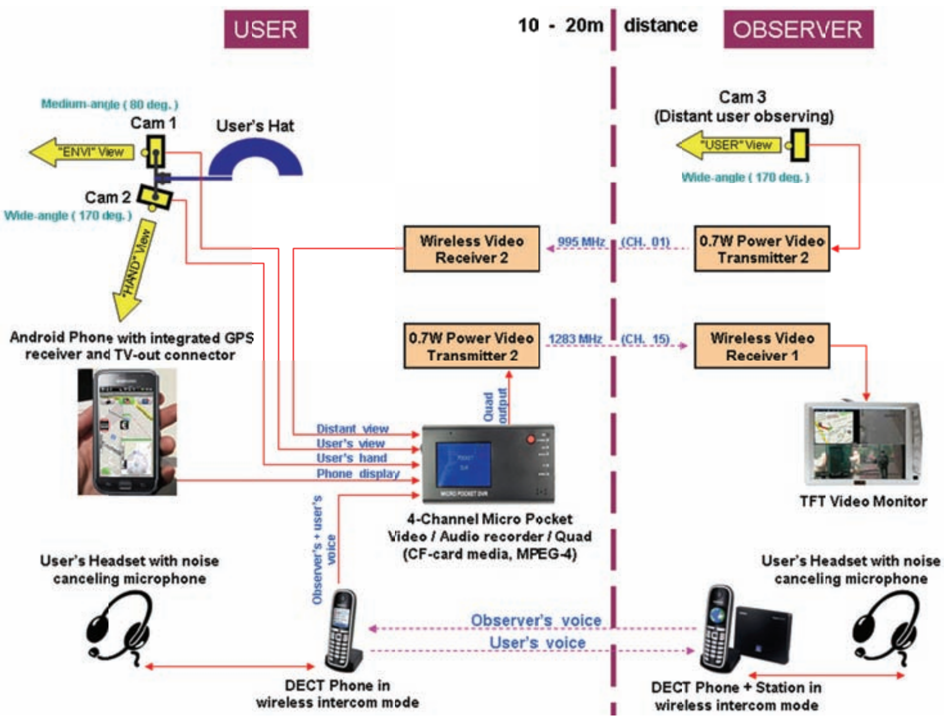


Figure 6.2: The new version of the field-based remote observation / recording system.

6.2.5 Pre-selection questionnaire and post-session interview

Considering the fact that the TPs should represent the actual target users of LN, they should be unfamiliar with the test areas. This could be checked through a pre-selection questionnaire from which a general profile of the TP could be generated. Through that, the TP's background, knowledge and experience especially in disciplines relevant to the ones of the test could be investigated. The pre-selection questionnaire questions are shown in Appendix 4.

To further justify the thinking aloud and observation findings but also to gather more information regarding particular parts of the experiment where the TP showed interesting or unexpected behaviour, a post-session interview of semi-structured form will be used. Some of the questions that this testing aims at answering but cannot be easily extracted from thinking aloud and observation can be asked in this way directly to the TPs. The standard questions of this interview are shown in Appendix 6.

6.2.6 Briefing and training

The transportation of the TPs from Enschede to Amsterdam was scheduled to be done, as earlier described, by train. For TPs who came alone, the meeting point was Amsterdam Central Station. During the transportation of the TPs from Enschede to the test areas by train together with the researcher the TPs received a clear description of the experiment, instructions and precautions (e.g. the dangers of pick-pockets in Amsterdam). The literal instructions given to the TPs are presented in Appendix 5. After that the mobile device that was used for the testing, a Samsung Galaxy S 9000 Android mobile phone was given to them one by one (max. half an hour each) in order to get familiar with the functions and the use of it. That was necessary, as many of them did not have any experience with smartphones with touch screens, thus they needed time get to know how to execute basic functions on them. The LN prototype and the latest version of GM were installed on the mobile device and all their important functions were explained to the TPs. Then the TPs were asked to interact with the applications and ask questions if necessary. At the end, they were informed that the test would start as soon as they would reach Wibautstraat Metro station (for the first TP) or Dam Square (for the second TP).

If there were additional TPs per day, the briefing and training sessions took place in a small café near Amsterdam Central Station (given that the researcher was already in Amsterdam). The pre-selection questionnaire was given and filled-in by the TPs before the day of the testing. The briefing and instructions are shown in Appendix 2.

6.2.7 Pilot testing

Having established the setting, methodology and technical configuration of the experiment, it was necessary to examine the execution procedure of the usability testing beforehand. Pilot testing was therefore required, for assuring that the experiment could be executed smoothly and flawlessly in regards to the user's and researcher's task execution and the technical support tools involved. In this way, possible problems and issues with the current configuration could be traced and proper solutions could be applied before the actual user testing took place. It was particularly important to ensure that the TPs could understand the instructions correctly and execute each of the given tasks accordingly during the usability testing. Besides, determining whether the initially estimated maximum time needed for the completion of each task was sufficient or not was possible with the help of pilot testing.

To provide valuable information, pilot testing should be carried out in the same context of use as the actual usability testing and should involve TPs who are representatives of the target user population as well. Therefore, two pilot tests were performed in this case, one for each of the areas selected for the tests. The participants were unfamiliar with those areas, and were provided with the briefing instructions and training before the test sessions as presented in Section 6.2.8. Thereafter, they were asked to complete the tasks presented in section 6.2.2. The first pilot testing was held on 18th of July 2010 in the area of Amsterdam City Centre and the second one on 28th of July in the area of Wibautstraat.

The information gathered from the pilot tests was solely used for identifying problems in the structure and execution of the task-based usability testing. This implies that it was not regarded as part of the prototype evaluation research data which were analysed further. During the pilot tests, the following problems were identified:

First of all, the 2-way wireless video transfer of the field-based remote observation / recording system did not work as well as expected in the field, although there was no such problem during the laboratory trials. In many cases, a lot of noise and interference was observed in non-regular time intervals which made the video observation of the TPs problematic or even impossible. This was surprising, considering that more powerful video transmitters were used in this new system compared to the previous one (made for the requirement analysis experiment). A reason for that could be an increase of the electromagnetic background noise in the area of Amsterdam during the holiday season (July –August), due to the large amount of mobile phones used by tourists and other private or public wireless communication and security systems. To solve the problem, more sophisticated, highly selective video receivers should be used, which would be able to further reject the noise and improve the reception of the actual signal. However, that would be an expensive and difficult to implement approach given the resources available to this research. Thus, a simpler but highly effective solution was developed, using a 15m-long double video cable connection between the researcher and the TP. Disabling and bypassing the wireless video transmission and re-directing the 2-way video transfer through the cable proved to be a reliable and satisfactory alternative for all the test sessions (Figure 6.3). A disadvantage of that approach was that the researcher had to take good care of the cable when it was used, in order to avoid accidents when for instance a car or bike was passing between the researcher and the TP. The possibility that the cable connection could increase the awareness of the TPs that they are followed by the researcher was also considered. Thus a cable of the lightest weight and smallest diameter possible was used, always kept loose in order to make it unnoticeable by the TPs.

However, no one of the TPs complained about that during or after all the tests, although they did so for other things such as the weight of the camera hat or the unpleasant feeling of being observed by strangers during the sessions.

Figure 6.3: Using a temporary video cable connection between the researcher and the TPs to overcome wireless video transfer problems.

Besides the video cable problem, another problem discovered during the pilot tests was the instability of the positioning accuracy of the mobile device used (Samsung Galaxy S9000). As a matter of fact, SiRFstar III type GPS receivers, as the one used in the mobile device, are highly sensitive and provide very good accuracy. However, a poor implementation of the internal GPS antenna can largely deteriorate the GPS signal reception quality and that could be the case here as well. Besides the accuracy problems of the integrated GPS receiver when walking along the streets of Amsterdam, an automatic switching to GSM-based positioning was performed often by the mobile device, decreasing the localization accuracy even further. As a default function of Android-based devices, when the GPS signal is regarded as weak, nearby GSM tower positions are calculated in order to provide a rough estimation of where the mobile device is. The accuracy of this technique can be as low as 300m, making it practically useless for personal geo-identification and navigation in metropolitan areas. The switching from GPS- to GSM-based localization can create large "jumps" of the user's position on the mobile map leading to spatial confusion and annoyance. Connecting an external high quality Bluetooth GPS receiver to the mobile device would be a sound solution to that problem, but that function is not supported in the current implementation of the Android operating system, version 2.1. To cope with these issues a compromise had to be made. As long as the GPS receiver could not be replaced, the only remaining alternative was to create a software function of disabling GSM positioning when the prototype interface was running on the mobile device. This approach did not solve the problem completely, but it offered a noticeably better accuracy and stability than before.

An additional problem that was identified in the pilot testing was the overlapping of the destination flags on the mobile interface by other landmark icons in particular zoom levels, making the flags invisible. The pilot TPs could not locate the destinations easily and had to zoom-in and out several times in order to distinguish them. To address this issue, a modification in the landmark database used by the interface had to be done, giving the highest order to the destinations so that their flags always remain on the top of any other landmark icons (Figure 6.4).

The scaling of the landmark icons on the interface depending on the map zoom level also proved to be a source of trouble. During the pilot tests, the interface many times crashed during continuous zooming-in and out after using it for some time because of that icon scaling (as proved later). Besides that, the presentation of all the selected global landmarks on the map slowed down the response of the interface even during simple actions, such as zooming-in and panning. The reason for the latter was the amount of processing power and

RAM (Random Access Memory) needed by the interface for landmark visibility calculations. The larger the number of global landmarks used, the larger the amount of landmark visibility layers processed and consequently the amount of system resources needed.

Figure 6.4: Placing the destination flags always on the top of other icons.

After a lot of experimentation and considerations, two practical solutions were applied. For addressing the problem of landmark scaling, a set of different size icons for each landmark was formulated instead, each for a particular zoom level. This approach largely improved the interface response. The icon sizes are: 4x4, 8x8, 16x16, 24x24, 32x32 and 48x48 in PNG format and three examples of these sets are shown in Figure 6.5. Using the icon size sets instead of continuous icon scaling, the interface stopped crashing and the response to zooming-in and out was quicker.

Figure 6.5: Examples of landmark icon size sets. Icons of size 4x4 appear on the map as colourful dots (still clearly distinguishable).

Size 48x48 is now used in map zoom level 19 (maximum zoom-in level), size 36x36 in level 18, size 24x24 in levels 17 and 16, size 16x16 in levels 15 and 14, size 8x8 in levels 13 and 12 and size 4x4 in levels ≤ 11.

For addressing the problem of the high number of global landmarks, the ones which were very close to each other (≤ 100m) and at the same time far away from any point of the multi-paths (≥ 500m) were first identified and put into separate groups. Then, the global landmarks with the greatest height within each group were selected and the remaining ones were discarded. At the same time, it was decided to eliminate the global landmarks which would never be seen at any point of the multi-paths that the TPs would follow or in a distance of up to 100m from any part of the multi-paths. This 2-stage filtering process resulted in a reduction of the number of global landmarks from 97 to 22, improving the response of the interface dramatically.

As it comes to the time limits for each task, those were finalized to 28 minutes for each of the two routes in the Amsterdam City centre area (S1 to D1 and D1 to D2) and to 21 minutes for each of the two routes in the Wibautstraat area (S2 to D3 and D3 to D4). To define those limits, the average navigation times of the pilot testers and the researcher for each route were doubled and rounded to the closest integer (minutes) value.

6.2.8 Selecting and scheduling the test persons

In order to create a pool of prospective TPs from which 24 would be selected to participate in the usability test sessions, the easiest way to do so was through the academic channels (ITC, University of Twente). Moreover, special effort was given to find TPs outside that community to increase the participants' diversity as the former have above average involvement in maps. However, even if that would not be possible, the ITC and University of Twente (UT) community still comprised a valuable group of persons coming from different cultural and national backgrounds who are mostly largely unfamiliar with the study areas.

The first step was to electronically contact different departments, faculties and student organizations of UT using mailing lists. The student and staff members belonging to the above groups were informed about the aims, requirements and procedures of the experiment including the time needed for the completion of each test session. Their kind participation was asked for, offering in return to the ones that were selected a round-trip ticket to Amsterdam for free. This offer would give them the opportunity to spend their day there after the completion of the experiment, alone or together with their friends, colleagues or family members that could participate on the same day. Additional emails with the same contents were sent to individuals inside and outside academia that could be interested in participating, making use of online social networking groups (LinkedIn, Facebook). To all the persons who responded positively, a second email was sent, asking them to fill-in and return the pre-selection questionnaire provided (Appendix 4).

As expected, the largest number of responses (47) came from the Faculty of ITC, from people who have knowledge of geo-information and digital maps to a smaller or larger extent. To control the bias to the TPs resulting from that knowledge, it was decided to not allow their number to exceed 16 TPs (max. 2/3 of the test population).

TP NUMBER	GENDER	AGE GROUP	COUNTRY OF ORIGIN	BACKGROUND	PAPER MAPS	DIGITAL MAPS	GPS	MOBILE NAVIGATION SYSTEMS	SMARTPHONES	MOBILE GOOGLE MAPS	ORIENTATION IN NEW PLACES
TP1	M	31-40	Bulgaria	Molecular Bioengineering	2	1	1	1	2	2	4
TP2	F	25-30	Bulgaria	GI Science	4	4	1	0	0	0	3
TP3	F	18-24	China	GI Science	3	3	2	1	2	3	3
TP4	F	25-30	China	GI Science	3	3	2	2	2	2	3
TP5	M	25-30	Nepal	Environmental Science	3	3	3	0	1	2	3
TP6	M	31-40	Mexico	Oceanography	3	3	3	3	2	3	3
TP7	F	31-40	Chile	Chemistry, Oceanography	3	3	3	3	3	3	3
TP8	F	31-40	Georgia	Cartography, GI Science	4	4	3	3	4	4	4
TP9	M	31-40	Sweden	Surveying	3	3	2	2	2	2	3
TP10	M	41-50	Spain	Rural Resource Management, GIS	3	3	3	2	2	2	2
TP11	F	18-24	Ukraine	Geodesy, GIS	3	2	3	2	2	1	3
TP12	M	25-30	Namibia	Geography, Information science	4	4	4	4	4	4	4
TP13	F	25-30	Zimbabwe	Environmental Studies	3	3	2	4	4	3	4
TP14	M	18-24	India	Information Science, Engineering	3	3	2	2	3	2	3
TP15	M	31-40	Colombia	Computer Science	3	4	4	3	3	4	4
TP16	F	31-40	Tanzania	Computer Science	2	2	2	2	2	3	2
TP17	F	31-40	Peru	Civil Engineer	2	3	1	0	0	0	3
TP18	M	41-50	Netherlands	Electronics, Computer Engineering	3	3	2	0	0	0	3
TP19	F	18-24	China	Interaction Design, Product Design	4	0	0	0	2	0	4
TP20	M	25-30	Netherlands	Security	3	2	2	1	2	2	3
TP21	F	18-24	Mexico	Industrial design	1	1	0	0	2	3	2
TP22	F	18-24	Mexico	Industrial design	1	1	2	2	4	2	2
TP23	F	25-30	Indonesia	Computer Science, HCI	3	3	0	0	3	0	4
TP24	F	51-60	The Netherlands	Management assistant, yoga teacher	1	1	1	1	1	0	2

Table 6.2: The demographics of the TPs and their individual characteristics. TP17 to TP24 have no background in Cartography or Geo-informatics thus a different (pink) colour is used to distinguish them from the others.

The selection of 16 TPs out of 47 was based on their unfamiliarity with the test areas, their willingness to participate in the experiment on one of the days in the pre-planned period (31st of July 2010 to 15th of August 2010) and their response time. The number of responses from people without knowledge of geo-information and digital maps or academic background was 21 and the same selection process as above, in this case for 8 TPs, was applied.

The demographics and the individual characteristics of the 24 TPs, based on their answers to the pre-selection questionnaires that they gave, are shown in Table 6.2. Their level of knowledge in particular fields of interest for this research is presented through numeric values (0 to 4) in the table for simplicity reasons. Thus 0 refers to "none", 1 to "poor", 2 to "fair", 3 to "good" and 4 to "excellent". The TPs had various country origins and their gender distribution was 10 males and 14 females. Their age belonged to the range of 18 to 60 years old; they were mostly between 18 and 40. This distribution is not very far from a recent Nielsen Mobile Research study (The Nielsen Company, 2008) on smartphone use demographics that was done in the U.S.A. (Figure 6.6). The composition of the age groups in this research is presented in Figure 6.7.

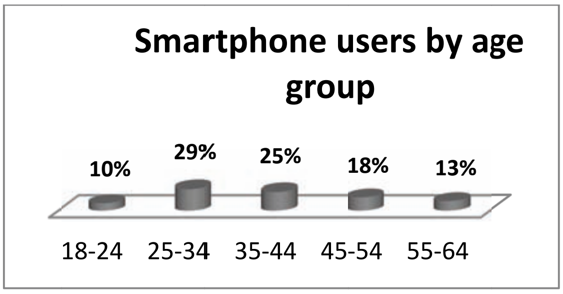


Figure 6.6: Smartphone users and age distribution in the U.S.A. (based on: URL33).

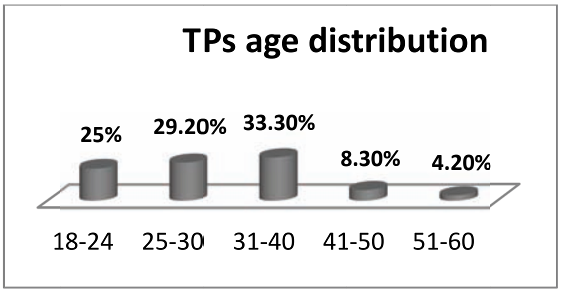


Figure 6.7: Age distribution of TPs in this research (n=24 respondents).

As it comes to the characteristics of the test population, the experience of the first 16 TPs with paper and digital maps and GPS systems appeared to be averagely good, while in the 8 remaining ones, it was fair. In regards to the experience with mobile navigation systems and GM, the earlier had a mostly fair to good level, while the latter a zero to poor. The same applies to the smartphone experience for the first 16 TPs, where the last 8 TPs had a poor to fair level. Lastly, the ability of all the TPs to orient themselves in new places was averagely good.

6.2.9 Test execution

The test sessions were conducted between the 31^{st} of July and the 12^{th} of September 2010, lasting for 43 days. This duration was almost double of what had been initially planned, based on which the TPs would be tested in two successive periods of 16 and 7 days. During the first period, the first 16 TPs would be tested and during the second the remaining 8 TPs. Although the first part of the plan worked as designed, the second one did not, as it took much longer time to schedule the test dates for the final group of 8 TPs. The reason for that was that many of them could not participate in the planned period due to personal and job-related issues. Besides, several tests had to be re-scheduled due to severe weather conditions (storms, heavy rain) during that time, delaying the completion of the tests until the 12^{th} of September.

In general, the tests were performed without significant problems in regards to the methodology. One researcher and one TP at a time was a convenient approach with low resource requirements. There were some technical issues, though, with the most serious of them resulting from a defect hardware part. That part was the Compact Flash card (CF) of the video recorder, where all the video and audio data were written to. After having recorded four consecutive test sessions, the data from the video recorder were always transferred to a desktop computer with a big storage space in order to empty the CF card. Although there was no indication that something was going wrong during the consecutive recording of TP1, TP2, TP8 and TP16, the CF card appeared to be corrupted and unreadable.

A large amount of effort was spent to repair the corrupted CF card and recover the contained data, but without avail. However, considering the available resources, it was decided to not re-do the tests of those 4 TPs with new participants and make use of the research material that was still available. That material were their post-session interviews, recorded into a separate audio recorder, and their task execution timings kept in an individual lap timer. The reason for using the latter was to prevent exceeding the pre-determined maximum time available for each task without the need for the researcher to keep notes and make calculations on the go.

The use of a video cable between the researcher and the TPs to overcome wireless video transfer problems produced really good results. In only one case (TP20) a sudden heavy rain during which the experiment had to be stopped resulted in a one-way connection loss for the remaining of the experiment. This happened because of the excess water that the video cable was exposed to, some of which entered the cable connections creating a signal short-circuit. Afterwards there was no picture on the video monitor of the researcher, thus the TP had to be observed directly from a much closer distance. The cable connections were reinforced and made totally water-proof after the end of the experiment to avoid a recurrence of the problem with the next TPs.

Rain in general was the reason for several stops and delays during or before the execution of the tests. The start of 6 sessions (TP1, TP9, TP18, TP20, TP21 and TP23) was delayed for 5 minutes (in case of TP23) to almost 01:30 hours (for TP9) because of rain. On the other hand, the test sessions of TP5, TP9 and TP20 had to be paused until the rain stopped for 25:47 minutes, 01:39 minutes and 18:55 minutes accordingly. A dry spot had to be found until it was safe for the electronic equipment and convenient for the researcher and the TP to start or continue the experiment. In 7 cases, when the rain was very slight and safe for the equipment, the experiment was carried out with the permission of the TP (TP2, TP5, TP9, TP15, TP18, TP20 and TP23).

Another reason for short delays were the interruptions by people asking about the aims of the experiment and the equipment used. This happened during the test sessions of 5 TPs (TP5, TP6, TP13, TP15 and TP21) and the duration of the delays was usually around 30 seconds but in one case it lasted for 05:02 minutes (TP15). The person who was asking about the experiment was a tourist guide from Canada, passing with his group of tourists. He was particularly interested in new forms of mobile maps which would support orientation and navigation of the tourists better. He was explaining that with current paper and mobile maps tourists are many times lost and they cannot find their way to the suggested tourist attractions which they want to visit. Landmark-based navigation in the form of LN was considered as promising by him. A few short delays to the execution of the test sessions were produced by minor technical problems as well. The most common of those problems was the loss of the video output from the mobile device used for the tests, which could be solved easily by unplugging and re-attaching the small video connector to it. Re-calibrating the integrated electronic compass and restarting the navigation interfaces after accidental pressing of the "back button" of the mobile device were two additional reasons for short interruptions of the experiment.

In the beginning of each test session, the researcher was preparing the electronic equipment and checking whether everything was connected properly and all the sub-systems were operational. This preparation required most of the time 4 to 6 minutes to be completed. The high-capacity lithium-ion battery packs were always recharged and carefully checked and measured in the evening before each testing day to ensure that there would not be any power shortage during the sessions. Following that procedure, there was not even a single power issue during the tests.

After preparing the electronic equipment for the tests, each TP was asked to go to the starting point and he or she was given a card with the first scenario representing the first orientation / navigation task (Initial Geo-identification) (see Section 6.2.2). After finishing reading it, he or she was asked to look at the sub-tasks related to the interface that was used, answer the questions and carry out the sub-tasks. The same procedure was followed with the second scenario, representing the second orientation / navigation task (Identification of Destination and Travel Decision). Completing both of the tasks the TP was asked to start moving towards the destination using the routing of GM or one of the two multi-paths in LN, for plenty or little time available, depending on the planned session structure. The TP was asked to stop at some point after having walked an estimated 75% of the distance to the destination and was given a card with the third scenario, representing the third orientation / navigation task (Route Confirmation / Route Control / Reorientation). The procedure of sub-task execution and answering was the same as with the first two tasks. When finishing with that task, the TP was asked to continue walking towards the destination and notify the researcher when he or she finds it. At that time, the fourth scenario was given, representing the fourth orientation / navigation task (Destination Confirmation).

Any significant action of the TP during his or her navigation to the destination, as for example a long stop or a sudden change of direction, was triggering the response of the researcher, asking the TP what he or she thought that was the reason for that. The answers of the TPs were combined with the observations of the researcher during the analysis of the research material in order to provide a more objective understanding of the TP's behaviour and the usability aspects of the interface.

6.2.10 Resulting research material

The research data acquired from the usability testing of LN comprised of three types of material: pre-test questionnaires, video / audio recordings of the test sessions and audio recordings of the post-session interviews. All of the resulting data files were re-named according to the TP numbers and the type of material. For instance, the data for TP3 includes: one document file named

TP3_pre-selection_questionnaire.doc, two video / audio recordings named as TP3_video_1.avi and TP3_video_2.avi and one audio recording named as TP3_interview.mp3. In this way it is easy to organize the data and perform searching and analysis activities faster. The total amount of video / audio files is 43, with an average of two per TP and a total size of 67.2 GB in MPEG-4 compression format. The size of the 24 interview files is 864 MB in mp3 320 kbps compression format. An example of the video recordings of the experiment, in the form of a screenshot, is shown in Figure 6.8.

Figure 6.8: Example of the recorded video material (screenshot).

The presented video frame shows TP18 near the starting point of the Wibautstraat area while clicking on a global landmark (Commercial / office building Rembrandt Tower) using LN interface in an effort to recognize it in reality and on the mobile map. The four different video signals which were captured synchronously and in real-time are shown together during the video playback. Each video signal displayed has an identification name on it such as "ENVI" (the environment in the viewpoint of the TP captured by the front camera on his hat) or "DISP" (the screen capture of the mobile device). At the upper left corner of the video frames, the actual time and date of the recordings are shown. This indication is very valuable for coding, analysis and searching of the data, as it comprises a direct reference to any particular moment of the test sessions. Carefully observing the presented video frame, the difference in the view angles of the "HAND" and "USER" cameras (wide) compared to the "ENVI" camera (medium) can be identified.

The resulting video and audio research data was a rich information source of quantitative and qualitative nature. Carefully analysing that data should reveal a series of usability problems with the interfaces used and provide directions for prototype re-design and improvement.

6.3 Analysis of the results

The first step in the qualitative analysis of the resulting research data was to interpret the results of each test session through verbatim transcription of the thinking aloud and screen and action logging from available recordings. In that way, the data could be transformed to an easily accessible form from which the problems, expectations, opinions and preferences of the TPs could be extracted.

Thinking aloud of the TPs along with their various actions, behaviours and reactions to different triggering events such interface (mal) functioning had been captured in the video / audio recordings. At the same time, different types of quantitative information, such as the number of stops due to disorientation, the number of times zooming-in / out was performed; the time needed for the completion of each task, the number of errors and so on could be measured. Thematic coding can then be applied for analysing the transcripts, grouping and identifying recurring and thus important events.

The verbatim transcription of the video and audio research material resulted into a 148-page long document. There, for each TP the session parameters (e.g. the test area, task completion times, and execution delays) are first provided. Then, the results of the TP for each task are given and every noticeable event during the task execution (TP's think aloud, important actions, errors and so on, are detailed. The exact time when the event happened is also provided to help searching, reviewing and further analysing the data. In the end, the answers of the TPs to each of the post-interview questions are provided. An example of the initial transcription results, and in particular for TP19, is shown in Appendix 7.

The transcript of the video and audio research material constituted a source of very rich and valuable qualitative and quantitative information from which the answers to the usability questions presented in section 6.2.1 can be acquired. Those questions aim at evaluating the different design aspects and technical solutions applied to LN. However, it would not be possible to get those answers without using a structured methodology for extracting this information from the transcript. Coding the different text segments of the latter using the qualitative research software Atlas.ti (Atlas.ti, 2010), was a convenient and straightforward way to do so. Twelve codes were defined, each referring to a particular action or state of the TP. These codes are presented in Table 6.3.

A: aborting task	**P: positive comment**
B: software / hardware bug	**S: successful execution**
C: confusion	**U: usability problem**
E: error / fail	**V: verification**
H: help needed	**X: user stopped**
N: negative comment	**Z: doing zoom-in / out**

Table 6.3: The codes defined and used for the analysis of the transcript.

The codes, associated with particular segments of the transcript, were connected to comments from the researcher in order to identify important usability issues. Completing the coding, it was possible to identify patterns and important aspects in the research material. An example of part of the coded transcript using Atlas.ti is shown in Figure 6.9.

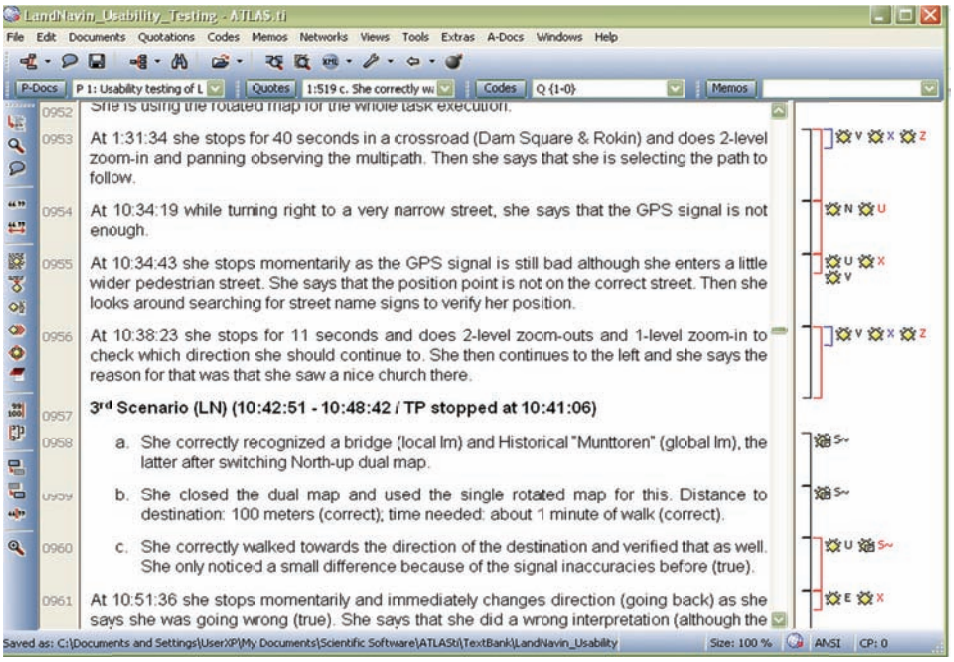


Figure 6.9: Coding the transcript with the help of Atlas.ti.

6.3.1 Outcomes of the analysis – task execution

Navigation performance

The four tasks of the usability testing experiment comprised of several sub-tasks that the TPs had to complete. Most of the sub-tasks constituted short assignments of orienting, locating landmarks, retrieving and verifying information, using interface functions and so on. However, to assess the performance of the TPs when navigating from a starting point to a destination, two longer-duration sub-tasks had been added at the end of both Task 2 and Task 3. During these sub-tasks the TPs were let free to use any available information and follow any path they decided to in order to find the given destination and go there. The outcomes of sub-tasks 2g and 3d are very important for this research, as they provide an overall evaluation of the efficiency and effectiveness of the interfaces used for the tests. Thus they are presented first here, before any other result. Table 6.4 presents the navigation times of all the TPs who participated in the experiment. In this table, "Seq" refers to the sequence in which each interface was used by the TPs, indicated with a direction arrow. For example, TP3 used first LN and then GM, thus the direction of the arrow is from the left (LN time column) to the right (GM time column). The type of quantitative data presented in Table 6.4 can be used for comparing the efficiency (duration) and effectiveness (completion) of the two interfaces in navigation tasks.

All of the TPs were able to successfully complete sub-task 2g with LN, while two TPs (TP1 and TP24) failed to do so using GM. TP1 belongs to the TPs with a background in geo-information science and TP24 to the ones with not such a background. The reason of failure for TP1 was that he exceeded the pre-determined maximum total time for the GM-based part of the task (28 minutes). When that happened, he still was in the middle of the route. TP24, on the other hand, decided to not complete the task with GM as she found herself totally disoriented and confused, being unable to relate reality and the mobile map. Although a decent amount of effort was spent by the researcher to comfort and encourage her to continue with the task, she refused to do so. An interesting fact is that TP24, although failed to complete the 4 tasks with GM, was at the same time the fastest TP with LN.

As it comes to the navigation execution times, the number of TPs who performed faster with LN was larger than the number of the ones who did that with GM. This is an interesting finding, as half of the TPs were following the multi-paths of LN for plenty of time available. An easy explanation would be that a fast path was still selected by those TPs, so they performed well. However, a closer look at the table reveals that the performance of the TPs using either LN with plenty of time available or GM was equal. At the same time, their performance using LN with little time available was exceptionally better (8 against 4) than using GM. The sequence of interface use is not an influence factor for these results, as it was interchanged for each TP. Comparing the time results of the TPs who used LN first (half of them) to the ones who used it second, it appears that the first group performed better in both of the test areas. A possible explanation for this result is that the TPs using LN first got used to its rotating map, thus could not perform as well when they had to execute similar tasks with the solely North-up map of GM. In many cases during the experiment, it was observed that those TPs were still expecting the map to rotate when using GM as they had forgotten that this function was not available with it. Considering the above, a competent performance of the prototype is observed, despite the fact it is only the result of a single design and implementation iteration.

TP Nr. (Group)	Area / Time / Interface sequence											
	Amsterdam Centre						Wibautstraat					
	Little time			Plenty of time			Little time			Plenty of time		
	LN	seq.	GM	LN	seq.	GM	LN	seq.	GM	LN	seq.	GM
TP1 (A)				16:24	→	Fail						
TP2 (B)										11:34	→	10:03
TP3 (A)	11:58	→	13:31									
TP4 (B)							9:13	→	11:55			
TP5 (C)				13:21	←	21:11						
TP6 (D)										12:27	←	10:10
TP7 (C)	15:50	←	15:51									
TP8 (D)							12:07	←	13:56			
TP9 (A)				20:00	→	17:50						
TP10 (B)										7:39	→	15:59
TP11 (A)	13:12	→	16:10									
TP12 (B)							14:04	→	14:54			
TP13 (C)				25:53:00	←	13:40						
TP14 (D)										10:33	←	9:12
TP15 (C)	13:29	←	11:52									
TP16 (D)							11:19	←	13:40			
TP17 (A)				13:07	→	17:20						
TP18 (B)										11:13	→	15:08
TP19 (A)	19:31	→	16:24									
TP20 (B)							12:24	→	11:02			
TP21 (C)				18:13	←	27:28:00						
TP22 (D)										20:03	←	13:07
TP23 (C)	13:32	←	12:43									
TP24 (D)							8:33	←	Fail			

Table 6.4: Time spent solely for navigation to the destinations (sub-tasks 2g and 3d) by each of the TPs. Each TP group is represented by a unique colour, in line with Table 6.1.

In order to visually compare the times that each group of participants needed to complete navigation, three charts were made based on the data presented in Table 6.4 (Figure 6.10). In the first chart (a) the average times of all the TPs for each group are shown, in the second one (b) the minimum times and in the third one (c) the maximum times amongst all of the participants of each group in minutes:seconds measurements. The most important is chart (a), as it is a clear indicator of the efficiency achieved by using each interface in regards to navigation.

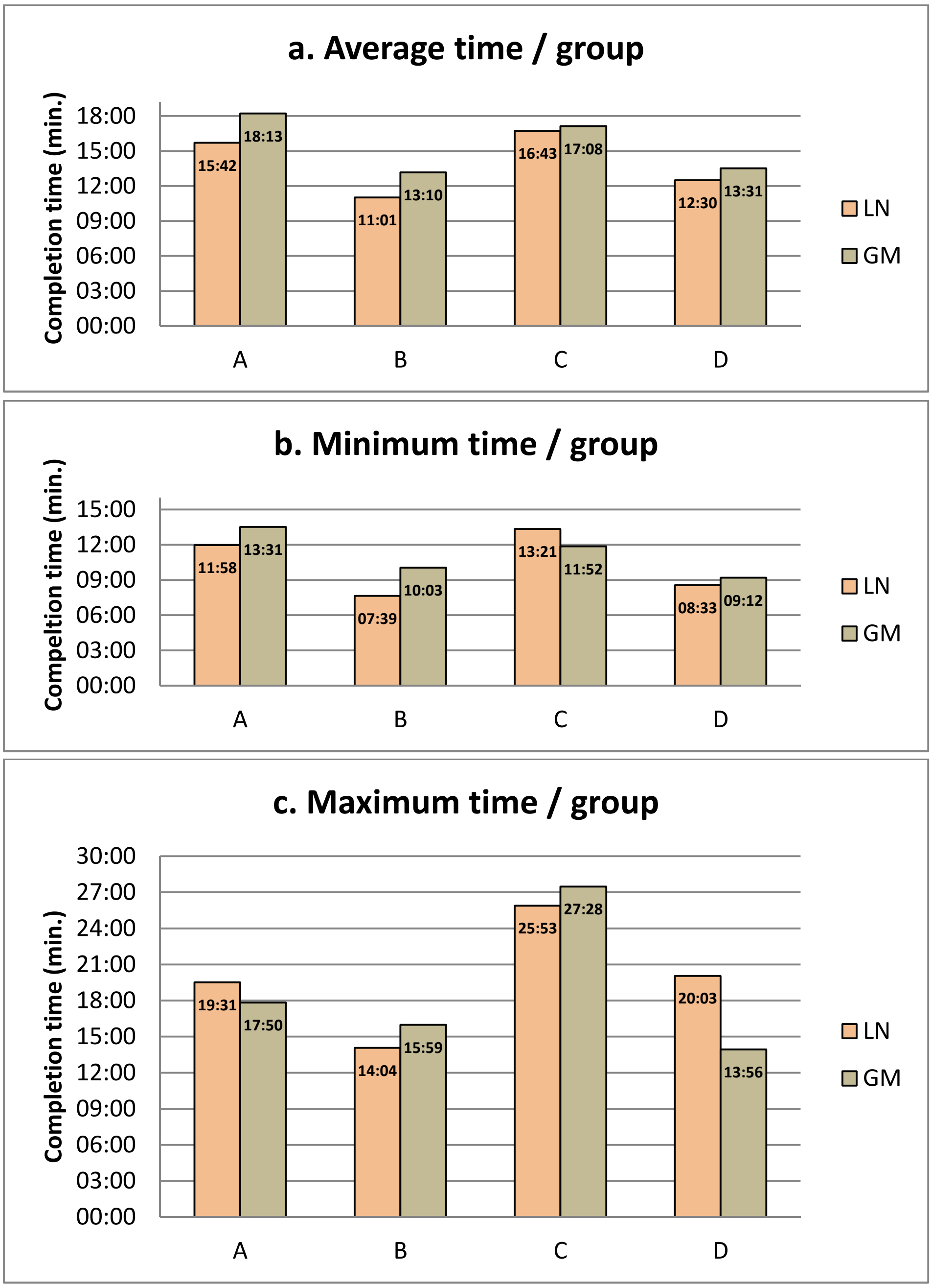


Figure 6.10: Efficiency measurements for the navigation sub-tasks 2g and 3d.

To calculate the averages for groups A and D using GM, the maximum task times allowed were assigned to the TPs who failed (28 minutes for TP1 and 21 minutes for TP24).

All the four TP groups (A, B, C, D) (see description of Table 6.1) resulted in better task completion times using LN in comparison to GM. This indicates that regardless the structural density of the unfamiliar area or the sequence in which each of the two interfaces was used, the TPs could perform better with LN. As it comes to the minimum task completion times that the TPs demonstrated, three out of four groups (A, B, D) achieved them with the use of LN. Regarding the maximum completion times, half of the groups (B, C) performed better with LN and the other half (groups A, D) with GM. However, for this result the fact that half of the participants of each group were using LN with a multi-path for plenty of time availability should be taken into account. In that case, although most of the TPs tried to follow a route that would bring them to the destination without making big rounds, many times they made use of alternatives which were not the shortest paths. Besides, the majority of the TPs (18 out of 24) had some experience with the GM interface in the past, fair to good in average, being familiar with it, while they used LN for the first time. Considering all the above, it may be concluded that the TPs navigated noticeably more efficiently and fairly more effectively with LN than with GM for the same given task.

During sub-tasks 2g and 3d, the TPs were following their selected route in order to reach the destination. The most important reason for spatial confusions and directional mistakes during that task was the inaccuracy of the GPS positioning about which the majority of the TPs had complained. The position / orientation arrow on the map remained the basic source of information and determined in many cases the trust of the TPs in the interface. The number of navigation stops that they made comprises an indirect indicator of the efficiency of the interfaces but also depends on the orientation and navigation capabilities of the TP (Table 6.5). The reported stops were only the ones made by the TPs and not induced by the researcher or other external triggers. As it comes to the average number of stops per group of TPs, 3 out of 4 groups (A, C and D) performed better with LN. A graphical representation of the results presented in Table 6.5 is shown in Figure 6.11.

To evaluate the usability of the LN prototype alone and in comparison to GM, the results of each of the user tasks (see Section 6.2.2) will be investigated first. To do so, the obtained qualitative and quantitative data per task will first be reviewed, extracting the observed usability problems and applying effectiveness measurements (task completion rates per interface) to the results. Based on the identified usability problems, particular solutions will proposed in the next section (6.4.3).

Group	TP	Task 5	
		Number of stops for verification or re-orientation	
		LN	GM
A	TP1	-	-
	TP3	3	5
	TP9	3	4
	TP11	5	7
	TP17	1	3
	TP19	7	3
B	TP2	-	-
	TP4	3	2
	TP10	3	4
	TP12	2	1
	TP18	1	1
	TP20	2	0
C	TP5	3	12
	TP7	9	9
	TP13	11	13
	TP15	1	2
	TP21	7	9
	TP23	1	4
D	TP6	1	5
	TP8	-	-
	TP14	0	0
	TP16	-	-
	TP23	1	4
	TP24	1	7

Table 6.5: Number of stops during navigation.

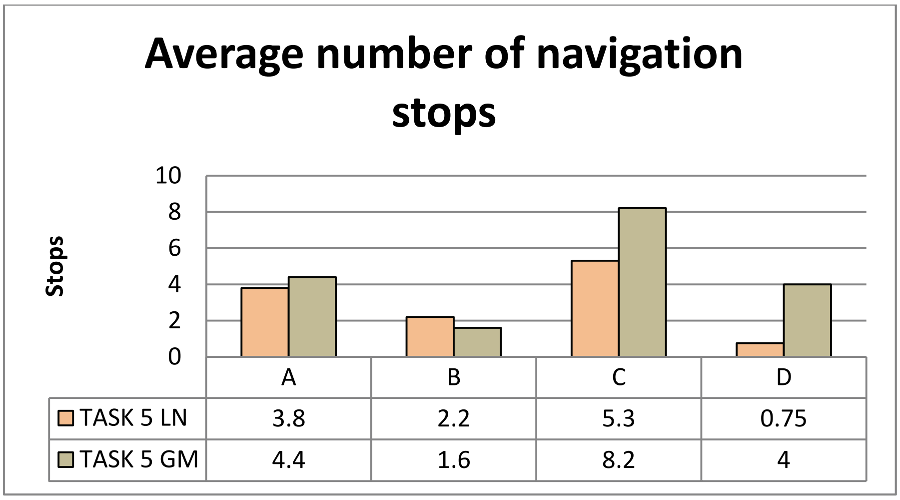


Figure 6.11: Average number of stops per TP groups during Task 5.

Task 1 (Initial Geo-identification): During that task the TPs were asked to orient themselves in an unfamiliar area, trying to understand where they exactly are and what are their surroundings. They were encouraged to find reference points around them, and in particular landmarks, which would help them carrying out this task. In the beginning of the task (Task 1a), their opinion regarding the success of the briefing / introduction session as it comes to their obtained familiarity with the interfaces was investigated. Most of the TPs stated that they had enough time to get familiar with LN, except one (TP6) who thinks that more time would be good to get used to it. As it comes to GM, three TPs argued that they would probably benefit if they had more time to learn the interface stating that "I guess I would need more time. Probably 5 minutes more would be ok" or "I could do with more but I understood".

Sub-task 1b tested whether the TPs were able to change the view of the type of the map using the software controls, and indirectly assessed their familiarity with the functions of the interfaces. In general, the TPs did not have any difficulties except for four TPs who needed some kind of help in order to complete that task. Two TPs who had difficulties with GM when they had to use that interface first, and the two TPs who had difficulties with LN had to use that after having used GM.

Sub-task 1c in case of LN (this was not available for GM) assessed the ability of the TPs to recognize the landmark filtering on the map. Four TPs could not find out about that, while in the case of one of them there were no landmarks on the map to observe their filtering due to a software bug. Although this number of TPs is relatively small compared to the total number of TPs, a further, more visible indication of the landmark filtering is suggested to make the users aware of it. The proposed solution (S1) is described in Section 6.4.3.

Sub-task 1d inspected the ability of the TPs to recognize prominent landmarks of the environment on the mobile map. During that task, more than half of the TPs using LN were able to recognize prominent landmarks on the map and less than half using GM. Six of the latter had changed the map to satellite view in order to carry out the task. The main problem with both the interfaces was the difficulty to identify prominent landmarks in areas with low structure diversity and if they were identified, they did not exist on the map. This was more obvious in the Wibautstraat area but also in the area around the first destination of Amsterdam centre (Bijbels Museum). There, any small bridge, canal, park or even differently coloured building can act as a prominent landmark and it becomes important for the user. This is the general problem of different users choosing different landmarks and it is difficult, if not impossible, to show all possible landmarks. A proposed solution to that problem is S2 (Section 6.4.3).

Sub-task 1e investigated the legibility of the landmark photos provided by the interface. During that task, the majority of the TPs complained about the very small photos in GM, while some of them complained about the wrong angle of the photos compared to reality especially for GM. In the case of LN, many times the global landmark photos could not be recognized, because they were not visible from the particular position of the TP. A possible solution to that problem is S3 (Section 6.4.3).

Sub-task 1f intended to check whether the TPs could find a near-by landmark, such as a transportation station or stop. Then estimate the distance and time needed to reach it and the correct direction of it with the help of the mobile interface. The basic aim of this task was to evaluate the usability of the rotated map, the on-screen compass and the scale bar in finding directions and estimating distances. Most of the TPs used the rotated map of LN during that task and three of them a combination of North-up and rotated map. Only two TPs could not estimate the direction of the point correctly with LN. TP16 could not find the correct direction as she could not understand how he rotated map works and TP24 claimed that she could not estimate the direction of that point at all. The latter TP had difficulties with the use of the rotated map in the beginning of the LN session but performed very well after using that for a while and getting more familiar with it during the experiment. With GM, 7 TPs wrongly estimated the direction of the point, with TP19 and TP24 being 180 degrees out of the correct one. All the 7 TPs, however, correctly estimated the distance and time needed to go there using the automatic calculation of GM. This result shows that the approach of LN worked pretty good and resulted in very good efficiency and effectiveness of the task execution.

Sub-task 1g aimed at testing the ability of the TPs to correctly orient themselves and move in the direction of a non-visible landmark which could only be identified on the mobile map. Again, the usability of the rotated map and the compass were mainly investigated in this task. With the use of LN, there was only one TP who initially got confused because she misunderstood the state of the North-up / rotated map button. She thought that the map was the rotated one, while she was actually using the North-up. However, in the end, she understood her mistake and moved in the correct direction to the destination. With GM, 8 TPs moved into the wrong direction sometimes as much as 180 degrees out of the correct one (TP24) and one of them (TP4) refused to complete the task due to spatial confusion. This result again shows a very good efficiency and effectiveness of the rotated map.

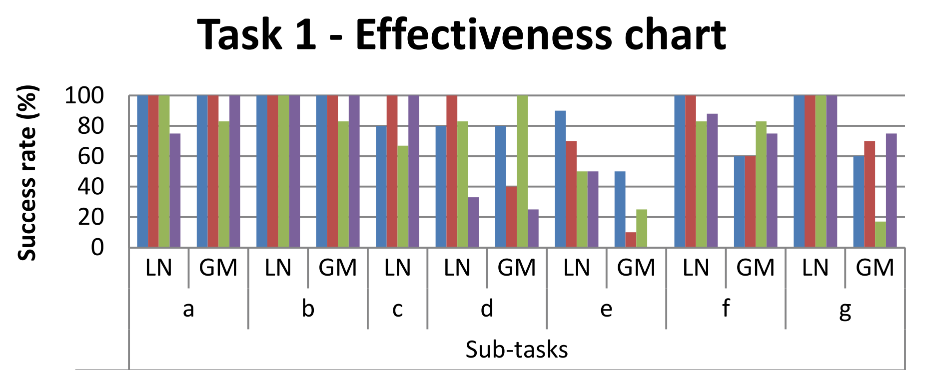
The effectiveness achieved by the TPs in terms of question answering success using each of the two interfaces for this task is detailed in the form of a table (Table 6.6). Y refers to successful, N to unsuccessful and P to partly successful sub-task completion. N/a refers to not available information (task not done or there was a data loss). Each group of TPs is represented with a unique colour, in line with Tables 6.1 and 6.4 for easy distinction. There are no data available for TP1, TP2, TP8 and TP16, so a hyphen is put in all of their sub-task results.

Group	TP	Task 1 sub-tasks												
		a		b		c	d		e		f		g	
		LN	GM	LN	GM	LN	LN	GM	LN	GM	LN	GM	LN	GM
A	TP1	-	-	-	-	-	-	-	-	-	-	-	-	-
	TP3	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	N	Y	N
	TP9	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	TP11	Y	Y	Y	Y	Y	N	Y	Y	N	Y	Y	Y	Y
	TP17	Y	Y	Y	Y	Y	Y	N	P	P	Y	P	Y	Y
	TP19	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	P	Y	N
B	TP2	-	-	-	-	-	-	-	-	-	-	-	-	-
	TP4	Y	Y	Y	Y	Y	Y	N	Y	P	Y	P	Y	N
	TP10	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	N	Y	P
	TP12	Y	Y	Y	Y	Y	Y	N	P	N	Y	Y	Y	Y
	TP18	Y	Y	Y	Y	Y	Y	Y	P	N	Y	P	Y	Y
	TP20	Y	Y	Y	Y	Y	Y	N	P	N	Y	Y	Y	Y
C	TP5	Y	P	Y	Y	Y	Y	Y	N	N	Y	Y	Y	N
	TP7	Y	Y	Y	N	N	Y	Y	N	Y	Y	Y	Y	N
	TP13	Y	P	Y	Y	N	Y	Y	N	P	N	P	Y	N
	TP15	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	N
	TP21	Y	Y	Y	Y	Y	N	Y	Y	N	Y	Y	Y	Y
	TP23	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	P	Y	N
D	TP6	P	Y	Y	Y	n/a	n/a	Y	N	N	Y	Y	Y	Y
	TP8	-	-	-	-	-	-	-	-	-	-	-	-	-
	TP14	Y	Y	Y	Y	Y	N	N	N	N	Y	P	Y	Y
	TP16	-	-	-	-	-	-	-	-	-	-	-	-	-
	TP22	Y	Y	Y	Y	Y	N	N	Y	N	Y	Y	Y	Y
	TP24	P	Y	Y	Y	Y	Y	N	Y	N	P	P	Y	N

Table 6.6: The results for all sub-tasks of Task 1.

The values of Table 6.6 can be represented graphically in the form of an effectiveness (success rate) chart where the comparison of the results between the different groups of TPs and the use of each of the interfaces becomes easier to interpret. To do so, "Y" could be replaced by "1" (success), "P" with 0.5 (partly success) and "N" with 0 (no success). Then the numerical sum of the resulting values of each group could be divided with the number of the involved TPs (for whom the results are available), producing a percentage of sub-task completion success. For example, the available results for group A and sub-task c done with LN are from 5 TPs: N, Y, Y, Y, and Y. These can be converted to 0, 1, 1, 1, 1, giving a summary of 4 which divided by the number of TPs (5), produces a value of 0.8 or 80%, as an indication of the effectives of completion for that sub-task. The effectiveness chart for Task 1 is illustrated in

Figure 6.12, where a table with the individual success percentages per group, sub-task and interface is also included.



Group	a LN	a GM	b LN	b GM	c LN	d LN	d GM	e LN	e GM	f LN	f GM	g LN	g GM
A	100	100	100	100	80	80	80	90	50	100	60	100	60
B	100	100	100	100	100	100	40	70	10	100	60	100	70
C	100	83	100	83	67	83	100	50	25	83	83	100	17
D	75	100	100	100	100	33	25	50	0	88	75	100	75

Figure 6.12: Effectiveness chart for Task 1.

In this illustration it can be observed that the worst average performance of all the groups occurred in sub-task 1e, using GM. In this task the TPs had to click on a nearby landmark and state whether they can recognize it from the provided information / photo. The average performance of the groups using LN for the same task appears to be significantly better, indicating that the bigger size of landmark photos and the multi-perspective photo feature results in easier landmark recognition. In sub-task 1d for GM a large deviation of performance between the groups is noted, with the Groups A and C (both in Amsterdam Centre area) exhibiting much better results. As this task has to do with locating noticeable landmarks around the starting position of the user, the problem of finding such cues in city areas with low structural diversity (e.g. Wibaustraat) is indicated here. A similar pattern of performance for the same task is demonstrated by LN, except group C which is very successful although the area of test is Wibautsraat. This can be an indication of the fact that in the starting point for Group C (Metro Station Wibautstrat) there were more noticeable landmarks visible (e.g. global landmark Commercial / office Rembrandt Tower). As it comes to the sub-task 1g, there is a very obvious difference of performance between LN (total success for all groups) and GM. This task tested whether the TPs can find the correct direction of a more distant landmark and the results demonstrate the high importance of compass-based heading maps for orientating activities.

Task 2 (Identification of Destination and Travel Decision): During that task the TPs were asked to select their destination, find more information about it and understand where its location is. They also had to estimate how far it is from them and how much time would be needed to reach it and then select a convenient path to go there. In the beginning of the task (sub-task 1a) the TPs were asked to select the pre-determined destination through the software buttons of the interface. With GM, 10 out 24 TPs asked for help to find the destination in the list. However, this had to do with the fact that the destination history of GM was used and many times it was difficult to find the particular destination required. In case of LN the destinations were directly accessible through a single click of a software button, thus only 1 TP asked for help to complete the task. However, the destination selection in LN was a simple solution to make it possible to execute the experiment and cannot be compared to the corresponding function of GM.

Sub-task 2b for LN (this was not available for GM) aimed at inspecting whether the TPs could notice the differences between the two multi-path routings to the destination offered, one for little and the other for plenty of time available. Only two TPs (TP10 and TP12) could not understand the differences, which is not a significant number. TP9 during that task complained about the plethora of landmark symbols on the map in the pre-selected zoom level for multi-path presentation of the whole route.

Sub-task 2c investigated whether the TPs could understand the position of the destination on the map and then estimate the distance and the time needed to go there. Five TPs underestimated the distance and time needed using the scale bar (in case of LN) while the others correctly presumed it. A solution for increasing the scale bar usability is proposed in S4 (Section 6.4.3). As it comes to GM, all of the TPs correctly estimated the distance and the time needed to go to the destination (this was automatically calculated by the interface).

Sub-task 2d had the aim of informing the users about the destination by clicking on its icon. All the TPs were able to complete that task successfully.

Sub-task 2e tested the ability of the TPs to identify the correct direction to the destination by walking towards that for a few meters. The combination of rotated map, visible multi-paths on the map and a highlighted destination icon was evaluated in terms of support given for that task. With LN, 2 TPs moved in a wrong direction (TP5 and TP6), one was initially confused but finally successfully finished the task (TP3) and another one (TP21), although having made a correct estimation, verified it wrongly after walking for 20 meters. As it comes to GM, 11 TPs moved in the wrong direction and one made a wrong estimation initially but verified it correctly after walking for 20 meters (TP23). Another TP claimed that "I cannot do that; it is very difficult to estimate the direction of the destination" (TP13). Considering these results, the superiority of the rotated map in comparison to a static map in finding directions is remarkable. However, the usability of the rotated map could be further improved, taking into account the confusion which is currently produced with the 10 seconds delay of rotation after clicking on the map. A proposed solution for that problem is given in S5 (Section 6.4.3).

Sub-task 2f for LN (not available for GM) checked whether the TPs could make a path selection in their mind using the multi-paths and then locate a few landmarks along that path for confirmation. All of the TPs were able to successfully complete that task, showing a good understanding of the way the multi-paths work and the role of landmarks along those paths.

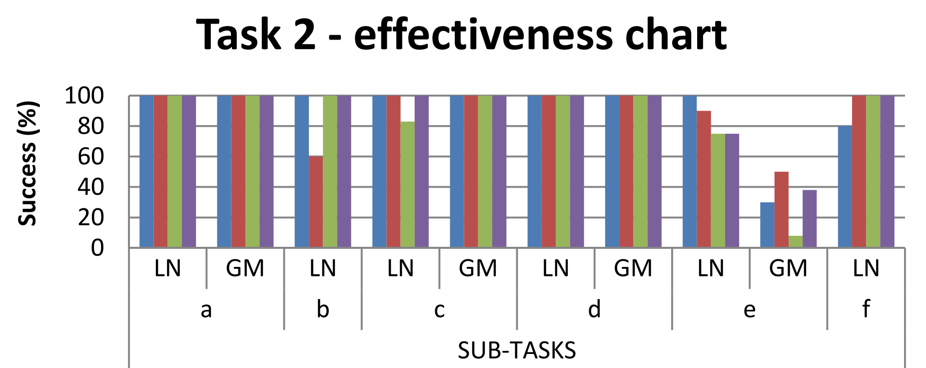
Group	TP	Task 2 sub-tasks									
		a		b	c		d		e		f
		LN	GM	LN	LN	GM	LN	GM	LN	GM	LN
A	TP1	-	-	-	-	-	-	-	-	-	-
	TP3	Y	Y	Y	Y	Y	Y	Y	Y	N	N
	TP9	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	TP11	Y	Y	Y	Y	Y	Y	Y	Y	N	Y
	TP17	Y	Y	Y	Y	Y	Y	Y	Y	P	Y
	TP19	Y	Y	Y	Y	Y	Y	Y	Y	N	Y
B	TP2	-	-	-	-	-	-	-	-		-
	TP4	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	TP10	Y	Y	N	Y	Y	Y	Y	Y	Y	Y
	TP12	Y	Y	N	Y	Y	Y	Y	P	N	Y
	TP18	Y	Y	Y	Y	Y	Y	Y	Y	P	Y
	TP20	Y	Y	Y	Y	Y	Y	Y	Y	N	Y
C	TP5	Y	Y	Y	Y	Y	Y	Y	Y	N	Y
	TP7	Y	Y	Y	Y	Y	Y	Y	N	N	Y
	TP13	Y	Y	Y	N	Y	Y	Y	Y	N	Y
	TP15	Y	Y	Y	Y	Y	Y	Y	Y	N	Y
	TP21	Y	Y	Y	Y	Y	Y	Y	P	N	Y
	TP23	Y	Y	Y	Y	Y	Y	Y	Y	P	Y
D	TP6	Y	Y	Y	Y	Y	Y	Y	N	Y	Y
	TP8	-	-	-	-	-	-	-	-		-
	TP14	Y	Y	Y	Y	Y	Y	Y	Y	N	Y
	TP16	-	-	-	-	-	-	-	-		-
	TP22	Y	Y	Y	Y	Y	Y	Y	Y	P	Y
	TP24	Y	Y	Y	Y	Y	Y	Y	Y	N	Y

Table 6.7: The results for all sub-tasks of Task 2.

The effectiveness achieved by the TPs in terms of question answering success using each of the two interfaces for this task is detailed in the form of a table

(Table 6.7). Y refers to successful, N to unsuccessful and P to partly successful sub-task completion.

The effectiveness chart of Task 2, based the results shown in Table 6.7 is shown in Figure 6.13. In this figure the problem that two TPs of Group B had in finding the differences between the multi-paths for plenty and little time availability are shown (sub-task 2b). A large difference of average group performance between LN and GM in correctly identifying the direction of the destination (sub-task 2e) is also observed. This result again manifests the usability of the compass-based heading map for orientation tasks.



Group	a LN	a GM	b LN	c LN	c GM	d LN	d GM	e LN	e GM	f LN
A	100	100	100	100	100	100	100	100	30	80
B	100	100	60	100	100	100	100	90	50	100
C	100	100	100	83	100	100	100	75	8	100
D	100	100	100	100	100	100	100	75	38	100

Figure 6.13: Effectiveness chart for Task 2.

Task 3 (Route Confirmation / Route Control / Reorientation): During that task the TPs were asked to confirm whether they follow a correct route to the destination by using spatial references (landmarks) that exist around their position. They were also asked to estimate their distance from the destination and the time still needed to reach it and to move towards the destination in a straight line. At the beginning of that task (Task 3a) the ability of the TPs to find information about landmarks along their route and towards the destination was evaluated. In case of LN, this had to be done using the dual map display in order to evaluate that function.

Although all the TPs were able to locate the local landmarks, 7 TPs could not find any of the global ones on the map. The reason for that was that they did not remember about the landmark filtering. Only 5 TPs used a combination of North-up and rotated map in order to find the (otherwise hidden in particular

North-up and rotated map in order to find the (otherwise hidden in particular directions) global landmarks and select the ones closest to the destination. This issue suggests a solution as described in S6 (Section 6.4.3).

Sub-task 3b investigated whether the TPs could estimate their distance to the destination and how much time would be needed to reach it. The usability of the moving scale bar in combination with the rotated map was again evaluated for LN in that task from a different point of the route, much closer to the destination. All the TPs successfully finished that task using LN, although 5 TPs made slight underestimations. Solution S4 is proposed to solve this issue as well here. Using GM it is pretty straightforward and automated to make distance and time calculations, so the TPs did not have serious problems completing the task.

Group	TP	Task 3 sub-tasks					
		a		b		c	
		LN	GM	LN	GM	LN	GM
A	TP1	-	-	-	-	-	-
	TP3	Y	Y	Y	Y	N	Y
	TP9	Y	Y	Y	Y	Y	Y
	TP11	Y	Y	Y	Y	Y	Y
	TP17	Y	P	Y	Y	Y	Y
	TP19	Y	N	Y	Y	Y	N
B	TP2	-	-	-	-	-	-
	TP4	Y	Y	Y	Y	Y	N
	TP10	Y	Y	Y	Y	Y	P
	TP12	Y	Y	Y	Y	Y	Y
	TP18	Y	Y	Y	Y	Y	Y
	TP20	Y	N	Y	Y	Y	N
C	TP5	Y	Y	Y	Y	N	N
	TP7	P	Y	Y	Y	Y	Y
	TP13	P	Y	Y	Y	Y	Y
	TP15	P	Y	Y	Y	Y	Y
	TP21	Y	P	Y	Y	Y	Y
	TP23	Y	Y	Y	Y	Y	P
D	TP6	Y	Y	Y	Y	Y	Y
	TP8	-	-	-	-	-	-
	TP14	Y	Y	Y	Y	Y	Y
	TP16	-	-	-	-	-	-
	TP22	Y	P	Y	Y	Y	P
	TP24	Y	N	Y	N	Y	N

Table 6.8: The results for all sub-tasks of Task 3.

Sub-task 3c inspected in a practical manner whether the TPs know the correct direction of the destination with the use of the interface, by moving towards that in a straight line. Two TPs using LN moved in the wrong direction while in one of them the reason was a software bug. With GM, 2TPs moved wrongly, one totally aborted the task as he said “I cannot move towards the direction of the destination” (TP20) and two TPs made initially wrong direction estimations but after walking they verified the correct direction.

The effectiveness achieved by the TPs in terms of question answering success using each of the two interfaces for this task is again detailed in Table 6.8. Y refers to successful, N to unsuccessful and P to partly successful sub-task completion. The effectiveness chart of Task 3, based the results shown in Table 6.8 is shown in Figure 6.14. An apparent difference of average performance of the TP groups between LN and GM in locating a local landmark along the route to the destination and one in the direction of the destination (sub-task 3a) is observed in this figure. Using LN the TPs were more able to complete that task, which was a matter of easier recognition of landmarks on the map. In sub-task 3c (verification of the direction of destination), the better average performance of the four groups with LN indicates for one more time the usability of the compass-based rotated map when orienting.

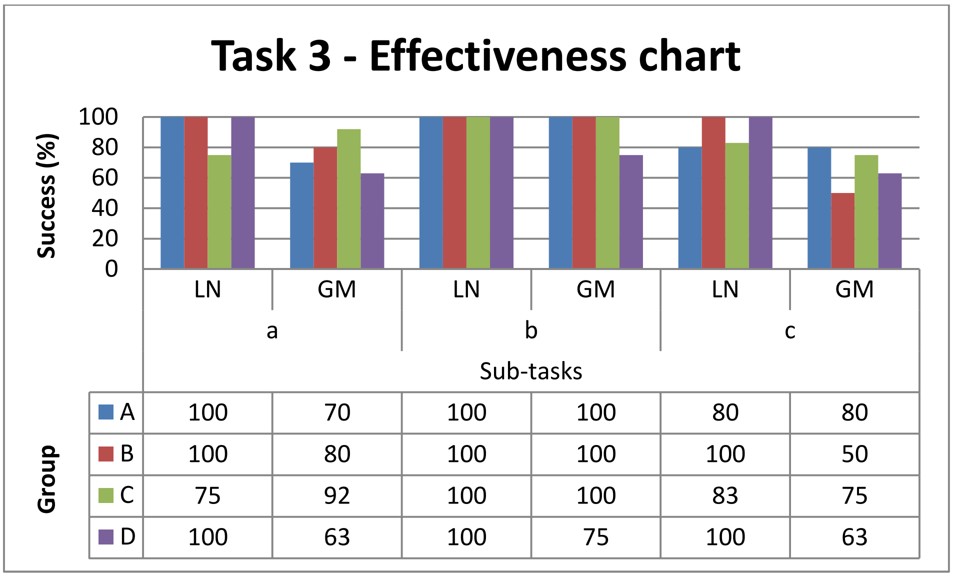


Figure 6.14: Effectiveness chart for Task 3.

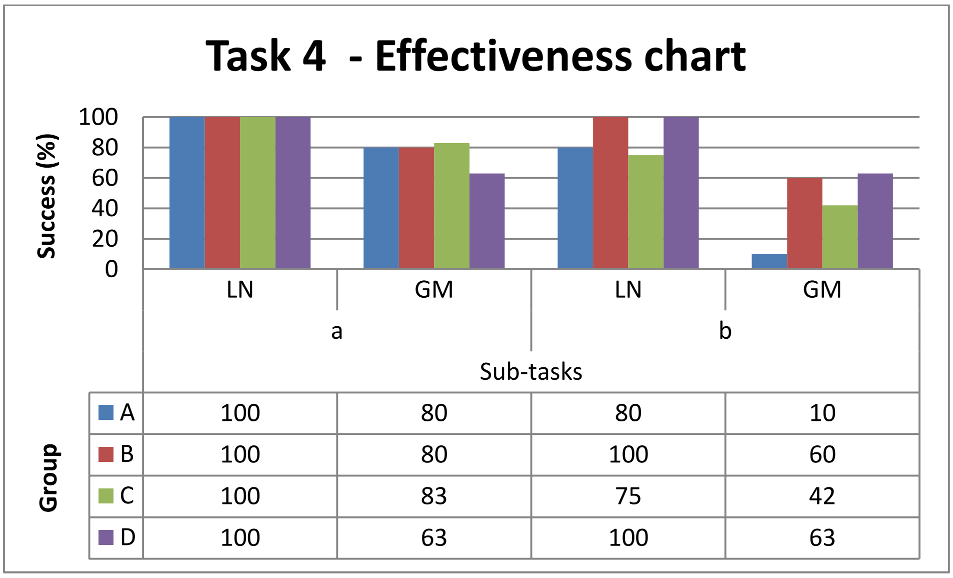
Task 4 (Destination Confirmation): During this task, the TPs were asked to verify that they had reached their destination and to try to recognize it on the map and through the provided destination photo. The aim of sub-task 4a was to check whether the TPs have a clear indication of the destination on the map in order to verify that they are there. With both LN, and GM, 2 TPs complained that the destination is not very clear on the map. This had to do with the size of the icon on GM and GPS inaccuracies in LN. Sub-task 4b assessed the quality and the eligibility of the destination photo. With LN, 3 TPs stated that the photo was taken from further distance and it was somehow difficult to recognize it while standing in front of the destination. 2 TPs claimed that the photo is not very recognizable in general. With GM, 10 TPs said that the photo was not recognizable, not very clear, very small or referring to a wrong building. Providing the TPs with more recognizable photos of the destinations implies that photos taken from different distances would be presented on the interface based on their position. Again, the solution S3 (Section 6.4.3) could be applied in this case as an additional reference to the destination.

Group	TP	Task 4 sub-tasks			
		a		b	
		LN	GM	LN	GM
A	TP1	-	-	-	-
	TP3	Y	Y	Y	P
	TP9	Y	Y	Y	N
	TP11	Y	P	Y	N
	TP17	Y	Y	P	N
	TP19	Y	P	P	N
B	TP2	-	-	-	-
	TP4	Y	Y	Y	P
	TP10	Y	P	Y	P
	TP12	Y	P	Y	N
	TP18	Y	Y	Y	Y
	TP20	Y	Y	Y	Y
C	TP5	Y	Y	Y	Y
	TP7	Y	Y	Y	N
	TP13	Y	Y	P	P
	TP15	Y	Y	N	Y
	TP21	Y	P	Y	N
	TP23	Y	P	Y	N
D	TP6	Y	Y	Y	Y
	TP8	-	-	-	-
	TP14	Y	Y	Y	Y
	TP16	-	-	-	-
	TP23	Y	P	Y	P
	TP24	Y	N	Y	N

Table 6.9: The results for all sub-tasks of Task 4.

The effectiveness achieved by the TPs in terms of question answering success using each of the two interfaces for this task is detailed in Table 6.9. Y refers to successful, N to unsuccessful and P to partly successful sub-task completion.

The effectiveness chart of Task 4, based the results shown in Table 6.9 is shown in Figure 6.15. In task 4a shown in the figure (verification of destination on the map while reaching it), all the groups have total success using LN, and a distinctively lower performance using GM. Providing a clear photo of the destination rather than a (not always correctly located) very small photo of a building façade was the reason for the results in sub-task 4b (destination recognition through the provided text description and photo). The average group performance in that task was apparently better with LN compared to GM. Besides that, there is also an interesting performance pattern amongst the four groups with the same interface used. Groups A and C with both LN and GM performed equally better than Groups B and D. An explanation for this result could be that the destinations used in Groups A and C (Wibautstraat: Super Market Albert Heijn and Café Dauphine correspondingly) were more distinct than the destinations used in Groups B and D (Amsterdam Centre: Bijbels Museum and Doelenzaal Musical Theatre correspondingly).



Group	a LN	a GM	b LN	b GM
A	100	80	80	10
B	100	80	100	60
C	100	83	75	42
D	100	63	100	63

Figure 6.15: Effectiveness chart for Task 4.

6.3.2 Interviews and direct feedback from the test persons

To evaluate the usability of LN, additional information was acquired from each individual TP through semi-structured interviews after they had finished their test sessions. Through the findings of the interviews, the user opinions regarding each technical solution applied and their satisfaction of using those solutions were outlined. Together with those, their recommendations regarding additional functions or improvements to the current technical approaches were collected. These recommendations can help formulating suggestions for the development of a future iteration of LN. In order to report the interview results, the answers of the TPs to each of the 15 interview questions, presented in Appendix 6, will be analysed sequentially.

In **question 1**, the TPs were asked to provide their general remarks regarding LN and GM. 22 out of 24 TPs liked LN and its functionalities and found it more useful than GM. Two TPs (TP11, TP19) expressed a neutral opinion about it. This result may show a tendency towards satisfying the researcher who developed LN. However, when TPs were asked to justify their statements, they provided decent evidence to support these, by referring to different parts and functions of the prototype which helped them with their tasks. The experimental results validate this finding to a large extent as well.

The functionalities that were especially commented upon positively by the TPs were the map rotation (17 TPs), the way landmarks appear on the map (6 TPs), the pop-up information and the landmark photos (6TPs) and the multi-paths (5 TPs). In general, the TPs found LN less confusing, more helpful in orienting themselves, more accurate, responsive and easier to use with more and new useful functions. On the negative side, GPS inaccuracies were the most important problem. Some confusion with the dual map for TP2 and with the landmark filtering for TP9 were also reported, while TP11 stated that with LN more time was needed to get used to beforehand. However, this TP added that she learned it fast through actual experience with it.

In **question 2,** the TPs were asked to identify which of the two routes they followed they remember better in terms of their surroundings and to reason that. The aim of this question was to investigate any possible relations between the use of each of the two interfaces with the development of mental maps of the test areas by the TPs. Out of 24, 14 TPs better remembered the surroundings of the areas in which they navigated using LN, 6 TPs using GM and 4 TPs did not find any difference. For those 14 TPs, LN was the first interface used for 3 of them and the second interface for the remaining 11 TPs. The landmark information on the map and its relation to reality was the reason for remembering that particular route for 10 of those TPs, the structure of the area for 1 TP, the rotated map and the increasing familiarity with LN for 1 TP, and the multi-path selection freedom for the last one. As it comes to the 6 TPs who remembered the areas where they navigated with GM better, for only one TP GM was the first interface to be used and the second one for the remaining 5 TPs. For three of those TPs, the reason was the structure of the area (canals, buildings etc.), for two the difficulty to orient themselves (which required more attention to the surroundings including street names etc.), and for one the freshness of the route in his mind. For all the TPs who did not find any differences, LN was the first interface to be used. Considering the above, it can be concluded that LN helped the TPs to construct better mental maps of the unfamiliar areas through the combination of technical solutions applied especially related to landmark use on the map.

In **question 3**, the TPs were asked whether they could easily understand their position and orientation with LN. From the 24 TPs, 21 answered positively to the question. From the remaining ones, TP19 answered negatively because of the GPS and compass accuracy problems that she had. TP16 had some difficulties getting used to the rotated map and TP24 had difficulties in the beginning of the task. However, the latter TP had the same problems with both the interfaces but in the case of LN the rotated map "kind of spoke" to her as she states. Thus she was able to understand her position and orientation easily after a few minutes of use. She argues, though, that for both the interfaces she would need more time to get familiar with it. For the 21 TPs who answered positively to the question, 7 TPs emphasized especially the rotated map, 1 TP the destination arrow (TP1), and another one the global landmarks as very helpful tools for orientation. The GPS inaccuracies as a source for disorientation were mentioned in total by 4 TPs (TP7, TP11, TP19 and TP23). TP3 proposed as a useful solution for her the rotation of street labels together with the map so that they always stay upside. Considering these answers to question 3, orientation with LN was easy and only a few problems were observed, mostly related to hardware sensors (GPS, compass) of the mobile device.

In **question 4**, the opinion of the TPs regarding the rotated map and their preference of using it alone or in combination with the North-up map was investigated. All of the TPs liked the rotated map and its functionality. Half of the TPs (12) found the rotated map alone good enough for carrying out any orientation and navigation task. However, three of those would like to have the option of a North-up map available (TP3, TP5 and TP9). 11 TPs would use the rotated map in combination with the North-up map and for different reasons: getting overview of the area and the destination (TP1, TP4, TP21 and TP23) or verifying things more easily, getting more details and more references (TP11, TP14). TP6 and TP16 claimed that they liked the rotated map, but during the tasks they did not use it (they did it only when they were asked for). Answering the question why that happened, they said that it was a matter of not enough familiarity with it. They actually would need more time to get used to the rotated map. Although she liked the rotated map, TP19 said that she was feeling nervous when using it, as she is used to paper maps and prefers to have a stable standard map view that she could rotate by herself. However, she still finds the rotated map very useful for particular moments of navigation when she would like to use it. In general, the rotated map was very well accepted by the majority of the TPs, and the combination of it with the North-up map would help them orient themselves and navigate with more easiness.

In **question 5**, The TPs were asked to evaluate the dual map, whether they could orient themselves with it understanding the relation between the two concurrent views (detail and overview) and whether the dual map reduced their need for multiple zooming-in and out. Out of 24 TPs, 11 liked the dual map and 13 did not like it or found it confusing. Amongst the ones who liked it, there were still complaints regarding the size of the small (detail) view which could not contain enough information (TP6, TP14), or the sizes of both views (TP20). Amongst the TPs who did not like it, there were complaints about the difficulty to understand and use it (TP2, TP5, TP9, TP12, TP13 and TP18), or the sizes of the views (TP11, TP4, TP6). There were also complaints regarding the zoom limits for each view (TP9) and the difficulty to use the basic functions when it is enabled (TP18). However, several TPs argued that more time was needed in order to get used to the dual map and then it would be probably more usable for them. All of the TPs except one (TP22) said that they easily understood their position on both views and all the TPs understood the relation between the two views, including TP17 who said that in the beginning that was a little bit difficult. As it comes to the amount of zooming needed with the dual map, 10 TPs stated that it was reduced and the remaining 14 TPs that it was the same as with the single map. To conclude: the dual map as a solution produced mixed results. Although almost half of the TPs liked the dual map or the idea behind it, in its current implementation the usability was low. The TPs needed time to get used to the function and got confused several times trying to understand how it works.

In **question 6**, the TPs were encouraged to express their opinion regarding the multi-paths, the easiness of finding their way based on them and the influence of time availability on the multi-path formulation. They were also asked to propose different presentation solutions for the multi-paths on the map if they found it needed. Out of 24 TPs, 21 liked the multi-paths and they found them more usable than the single routing of GM. Amongst them, TP1 proposes the development of an algorithm for calculation of the maximum walkable distance possible in the multi-paths based on time availability.TP4 liked them because of the combination with interesting landmarks on the map so that someone can for instance select a path full of shops or museums. TP6 found the multi-paths too much and suggests a reduction of them when no relevant landmarks exist along the path. And TP8 proposes an option for selection of the preferred paths in the beginning to reduce confusion. TP8, TP10, TP15 and TP23 suggest that only one path should be shown on the map for little time availability, the shortest one and no more alternatives of that. TP 23 also suggests that there should be 1, 2 or max. 3 alternatives for the multi-paths for plenty of time available as well. 21 TPs found it easy to navigate using the multi-paths, while 3 others (TP13, TP8 and TP15) got some confusion by seeing all the multi-paths on the map. Time availability influence on the multi-paths was regarded as a useful function by all the TPs except two: TP9 and TP19 who believe that time calculations can be done inside the mind and there is no need to present the results of them on the map. As it comes to the way the multi-paths appear on the map, half of the TPs propose that the shortest path should always be presented in a different colour than the alternative paths. TP5 and TP13 propose a different colour per path depending on the time needed to walk it or the amount of interest of the path. TP10 proposes a colour change for each of the paths that the user has walked already. Lastly, TP23 suggests giving different colours to the paths containing user-preferred landmarks (e.g. sight-seeing paths) making use of previous user feedback and municipality tourist information. Based on these answers to question 6, it can be concluded that multi-paths are a very successful idea which the majority of the TPs liked more than a single route. The time availability influence on the multi-paths was also regarded as a very useful option by almost all of the TPs. Indicating the shortest path with a different colour is a strong requirement coming out from half of the TPs thus it should be applied in a future iteration of LN. This solution is presented in S7 in Section 6.4.3. Besides, many different ideas regarding the colouring of the multi-paths based on different aspects of each path such as their distance, easiness, touristic interest, user route history and so on are discussed by the TPs, showing their large interest in the multi-path solution.

In **question 7**, the TPs were asked about the usefulness and accuracy of the global landmark visibility indication for them and the convenience of the way in which this information appears on the map. For the large majority of TPs (21) landmark visibility indication was a useful function. The remaining 3 TPs (TP9, TP21 and TP24) did not use it so much either because they found it confusing in the beginning, or they did not understand how it works. Amongst the ones who like it and used it, TP4 and TP15 say that if the global landmarks are not visible, they should not be on the map at all. TP13 complains that in Amsterdam there are many tall buildings which obscure the view of the global landmarks and that in another area this function would be more useful. Amongst all the TPs, TP18 and TP21 found the function a little confusing in the beginning and TP9, TP14 and TP19 the accuracy of the function not always very good. As it comes to the presentation of the landmark visibility on the map, TP4 proposes that the global landmarks should automatically pop-up when they are in the line of view of the user and they are visible. The visibility indication colour should also change according to TP17 and TP19 from blue to green, following a more standard colour coding approach. TP23 and TP17 on the other hand totally disagree with the colourful dotted circles as visibility indicators, as they find them distracting and map space consuming. They would prefer that the landmarks get a red cross (“x”) on them (TP17) or turn to grey when invisible (TP23). Although landmark visibility indication did not work 100% accurately for all the TPs or they did not have many chances to see different landmarks in both the states (visible / invisible) in both reality and on the map, most of the TPs found the function very useful. There are some suggestions for changing the way this information appears on the map, but the majority of TPs likes the current implementation of the idea.

In **question 8**, the opinion of the TPs regarding the pop-up information convenience and richness as well as the usefulness of the multi-perspective photos is asked. All of the TPs found the provided information adequate, but 8 TPs suggest the provision of additional information, preferably online, about opening hours, entrance fees etc. for touristic landmarks such as museums or monuments. TP10 suggests bigger landmark photos, TP12 more zoomed-in photos to help recognize the landmarks more easily and TP15 a larger number of landmarks accompanied by photos. TP8 and TP18 complain about the sometimes wrong aspect ratio of the provided photos which can produce confusion to the users, while for TP20 it is more important to get little but correct, up-to-date information. For 22 TPs, multi-perspective photos are very useful and important to recognize the buildings from different angles. Only TP 14 and TP 19 disagree with that, saying that it is enough for them to have only one landmark photo to be able to recognize it from different positions. To summarize, the pop-up information was very useful for the TPs, and it can be more useful if enriched with online, landmark-specific details. More attention should be given to the landmark photos, trying to reduce any geometrical distortion involved. These suggestions are presented in S8 and S9 of Section 6.4.3. The multi-perspective photo function was very well accepted and appreciated by the TPs.

Through **question 9**, the size, scaling and comprehensibility of the landmark icons and symbols was evaluated. For 18 TPs, the scaling of landmark icons was ok. However, 7 TPs noted that the icons become very crowded when doing much zooming-out and they cover each other on the map. They propose that they should be smaller or even dots in those zoom levels (TP11) and an option for disabling particular types for the map should also be available (TP18, TP21, TP22, TP24). TP24 states that transportation stations / stops should always be on the map and should not be disabled. Another solution for avoiding map icon cluttering suggested by TP8, according to which the non-important landmarks should become semi-transparent while the destinations should become more highlighted than what they are in the current implementation. Icon cluttering is one of the mobile map problems that have been recently investigated by Looije (2008), in the framework of the UWSM2 project.

The vast majority of the TPs easily understood the landmark icons and symbols without problems. Based on the answers to question 9 it can be concluded that the size and scaling of the landmark icons for the different zoom levels should be further optimized in order to reduce current cluttering (S11 in Section 6.4.3). Manually disabling particular landmark types is a convenient solution to the same problem (S12 in Section 6.4.3). However, the possibility that the user prefers to not disable any of the available types should also be considered as possible. So, a more advanced selection strategy based on landmark hierarchy should be studied and applied afterwards. The used symbology of the landmark icons, on the other hand, proved to be adequate for the TPs and should not be changed.

Question 10 coped with the helpfulness of the moving scale bar and the rotating compass. All the TPs except 3 found the moving scale bar helpful for their tasks. Out of these 3, TP1 did not notice its existence and TP10 and TP 19 prefer a fixed scale bar. TP9, although he found the moving scale bar useful, argues that this was the only available tool for distance and time calculations. He suggests that there could be additional ways of performing the same actions, as for example by clicking on two map points and getting a direct distance measurement on the map. TP15 would prefer to have round values inside the scale bar which would make the estimations easier and faster. The rotating compass was useful for only 6 TPs while another one (TP24) would like to see it on the map although she did not make use of it. Considering the latter, the rotating compass should be excluded in a next iteration, leaving more free space to be used by the map (S10 in Section 6.4.3). However, the option to manually enable it should still be available for the users who would like to use it. This could be done through a software sub-menu of the interface.

Question 11 investigated the convenience of the interface response to different user interactions and the understanding of the meaning and state of the on-screen buttons by the TPs. Out of 24 TPs, 21 stated that the interface response was fast enough for them and only 3 TPs complained about the slow response only when using the dual map (TP15 and TP17) and the annoyance of the 10 seconds delay on the map rotation after panning the map (TP11). TP11 believes that decreasing that delay to half (5 seconds) would be more convenient. In regards to the understanding of the on-screen buttons, 20 TPs found it easy, while three others (TP16, TP17 and TP22) faced some difficulties in the beginning but then it was ok for them. Only one TP (TP6) did not get a good understanding of the on-screen buttons in general.

In **Question 12**, the TPs were asked about the usefulness of the landmark filtering for them and the disabling of the function when the North-up map is selected. Out of 24 TPs, 19 found the landmark filtering useful and nice, as many of them added that it reduces the crowdedness of the map and makes it more clear by not showing landmarks that they do not see in reality as they are behind them. Out of those TPs, two TPs (TP11, TP22) would like to have the option of manually disabling the filtering for the rotated map sometimes and another one (TP23) noted that if the destination is behind her she could not see it. As this is true, she was explained that the destination is always visible on the map and not filtered in the rotated map. TP6, although he likes the function, finds it more useful for travelling than information provision purposes. One of the TPs (TP16) was asked why she claimed that she did not use the function during the testing while in the interview she claims that she likes it. She replied that she was still not very familiar with it. The 5 TPs (TP3, TP9, TP14, TP18 and TP19) who did not like the landmark filtering, would prefer to have all the landmarks available on the map at any moment as otherwise it can be confusing. As it comes to the disabling of landmark filtering in the North-up map, 19 TPs found it useful, the same TPs who liked the function of filtering. The remaining 5 TPs believe it is not important (TP3), or not needed (TP9, TP14, TP18 and TP19). In general, the filtering function was useful for the majority of the TPs. However, the number of the ones who prefer to have all the landmarks on the map always or when it is needed is almost one third of them (7 TPs). Thus it would be a good idea to offer a way to disable landmark filtering for the rotated map through a software button or sub-menu.

The problems that the TPs experienced during the use of LN which reduced their performance and possible improvements which would make it more usable for them were examined through **question 13**. In general, most of the TPs stated that they did not have major problems when using LN. The most important issue was the inaccuracies of the GPS and the compass, identified by 8 TPs. The majority of the TPs, however, implied that they could perform better with LN than GM although the GPS issue affected both of the interfaces. The second important problem was the icon overlapping, identified by 4 TPs. TP6 and TP 21 said that they had some difficulties to get used to the interface in the beginning of the tasks but after interacting with it for some time they became very familiar with it. TP2 noted that the scale bar colour should change to some else than red, as now it mixes with other colours on the map. TP4 got confused sometimes because of the destination arrow showing the direction of the destination in a straight line e.g. to the right while the path to go there was e.g. straight ahead. TP20 had some problems with the on-screen buttons which were pressed accidentally while she was doing other things, such as panning or clicking on a landmark icon. TP22 complained about a few software crashes that she faced during the task execution. Finally, TP24 was feeling disturbed sometimes to wait until the map refreshes when she was doing zooming-in or out. As it comes to ideas for improvement, the TPs mostly repeated the ones that they had already proposed during the answering of the previous interview questions. Again, the different colouring of the shortest or more interesting path in the multi-paths was discussed together with the filtering of landmark types based on the user's interests and the situation. Besides those, TP12 proposes voice guidance for the interface. When he is asked how this could be done given that the idea is to let the user free to select and change path all the time, he answers that the voice navigation would be performed only for paths which the user has selected in the beginning.

Whether the TPs would use LN for their future trips if it would be possible to have coverage of the city or city area of interest and the reasons behind that was the subject of **question 14**. The aim of that question was to inspect the overall feeling of the TPs towards LN and make an estimation of the amount of satisfaction that they get through the use of it. All the TPs except one (TP19) would surely use it if it was possible. TP19 still prefers the use of paper maps for navigation compared to LN and GM. The TPs in general reason their positive answer as a matter of the easiness and user-friendliness of LN alone and in comparison to GM. They state that it has more functionalities, saves time, creates trust, supports orientation better through the rotated map and the landmark information provided and it feels more comfortable and less confusing than GM. TP11 suggests that there should be an automatic calculation of multi-paths so that it can be used in future travels of his but he also understands the limitations of the prototype implementation. TP20, on the other hand, would like to have also an automatic pop-up of landmarks on the map when he is looking towards them in reality which would make LN even more satisfactory for him. Some of the answers of the TPs to questions 14 were: "Of course I would use it. It is easy and convenient, and I like the way it shows the map. It saves time" (TP5). "Yes, for sure, because you spend less time to find what you are looking for and feel more independent. I got satisfaction using it" (TP12). "Definitely. It really shows you where you go. I don't have to scratch my head and think" (TP13). "Yes, especially because of the map rotation which gives you a very fast and better indication of whether you are on the right track. With GM I was a bit disoriented when I started navigating and I needed more time to really verify where I am on the map and if I am going in the correct direction." (TP18). "Yes. It is very easy to see and recognize many things when you are on the street" (TP22). The above results indicate a satisfactory experience of the TPs with LN, often reflected into an enthusiasm towards possible future use of it during their trips.

Question 15 asked the TPs to express any additional comment, suggestion or idea that they had regarding the interface, the experiment and its execution. Most of the TPs stated that the experiment was nice and interesting for them. The equipment was sometimes a little uncomfortable for 4 TPs (TP 15, TP17, TP22 and TP 24). These TPs proposed the use of a helmet instead of a hat for better stability of the cameras on their heads. TP16 and TP 21 complained about the disturbance they felt from people who were curiously observing them while they were executing the tasks. TP3 would like to read the scenarios and questions of the tasks beforehand (during the train trip briefing). TP13 liked the distance between her and the researcher, which made her feel comfortable and behave more naturally.

6.3.3 Proposed solutions based on the usability testing results

Several usability problems of LN were identified during the task execution and the post-session interviews presented in the previous sections. Considering those and the valuable feedback acquired directly from the TPSs, the following solutions are proposed:

S1: To make the filtering of landmarks behind the user more obvious, a semi-transparent shadow should be put on the map whenever the rotated map is enabled. The shadow should cover the area of the map where the landmarks are filtered starting from the horizontal line of the user's position on the map.

S2: A richer database of landmarks is required from which a larger number of local landmarks should be presented to the user, automatically selected based on his or her current position. Detailed thematic maps should be super-imposed to the area of the street map surrounding the user's position. In this way, natural features could be recognized and used as reference points whenever the structural diversity of an area is low.

S3: As photos of landmarks are very important for the orientation and navigation of the users, they should always be available for places which can be directly located and verified by the user from his or her current position. To overcome the problem of directly collecting a huge amount of that type of data, software extraction techniques could be used to create snapshots from Google Street view based on the position and orientation of the user. These snapshots could then automatically pop-up on the map letting the user more easily verify his or her position and direction of movement.

S4: To ease the use of the scale bar for distance estimations, the scale bar could be made movable in the horizontal axis, so that the user could move it in the space between his position on the map and the position of the destination. An additional solution could be a pop-up window showing the distance of any clicked point on the map from the user's current position.

S5: Stopping the rotation of the map for 10 seconds after the user is clicking on the map was done for practical reasons, such as avoiding the rotation of the map around a wrong centre. It also allowed for an automatic return to the current position after those 10 seconds. However, that solution produced many problems to the TPs, as they were not sure many times whether the function is working or not and they were wondering whether the state of the North-up / rotated map is wrong. To solve that issue, the delay of 10 seconds should be decreased to a lower value, such as 3 to 5 seconds as proposed by several TPs. The exact value could be manually set by the user through a new software menu as well. If the user needs to observe an area away from his current position after doing panning for more than the selected delay time, he or she could just keep a finger on the screen. As long as this is done, the map will not return to the current position neither will it rotate.

S6: Global landmark filtering proved to be a source of confusion for the TPs. Although that functionality had been explained to them, it seems that most of them could not recall it, or it was too complicated for them to memorize. Thus it is proposed that the global landmarks should stay always on the map regardless the type of map used or the state of navigation. To avoid map overload, the global landmarks which are towards the direction of the destination could be presented in different size (bigger) than the remaining ones.

S7: To make the multi-path less confusing and to provide the users with an easily discriminated shortest path, the latter should be presented always in a different colour compared to the alternative, longer paths. A possible colour for that path could be blue or green.

S8: Online search results regarding the landmark of interest should be automatically acquired and included in the pop-up information windows. The user should be able to inspect this information in a full screen window on the top of the map.

S9: To make landmark photos easily and immediately recognizable, they should always be presented in a correct aspect ratio and in colours similar to the ones in reality during noon in average weather conditions for their area.

S10: The rotating compass should be excluded from the map and the user could enable it through a button in the software menu of the interface.

S11: The size of the landmark icons should be decreased for all the zoom levels to reduce cluttering.

S12: A new software menu should be added, allowing the user to select which particular types of landmarks from the available ones he or she wants to see on the map. However, a small group (3-5) of the closest important landmarks (either global landmarks of any type or transportation stations / stops) should always be visible regardless of the user's selection. In this way a possible disorientation of the user when landmarks of the selected type are absent from the map will be avoided.

6.3.4 Answering the usability questions

In order to assess the usability of the applied technical solutions in LN, the usability questions which were initially formulated and presented in Section 6.2.1 will be shortly answered, based on the results of the tests.

1) Position of the user and map orientation:

a. Q: Do the users easily and correctly understand their position on the map?

   A: Most of the times yes, and they performed better with LN than with GM.

b. Q: Do the users correctly understand their heading and direction of movement?

   A: Most of the times yes, and performed better with LN than with GM.

c. Q: Is the use of a rotated map towards the heading of the users based on digital compass useful and helpful for them in order to orient themsleves and navigate, or do they prefer a static map?

   A: Very helpful and useful for the task execution and the majority prefer it over a static North-up map. Half of the TPs would even solely use a rotated map for orienting themselves and navigating.

d. Q: Do the users use the North-up, the rotated map or a combination of them in order to carry out their tasks?

   A: Most of the TPs used a combination of the two map types.

2) Reverse overview+detail map

a. Q: Does the use of the reverse overview+detail map reduce the need for continuous zooming-in / out by the users or not?

   A: It reduced it for almost half of the participants.

b. Q: Does the use of the reverse overview+detail map help users geo-identify themselves correctly and relate reality to the mobile map with easiness or not?

   A: Yes, for the majority of TPs. However, the current implementation proved to be complicated and difficult to use for many TPs. Therefore, it has to be redesigned.

c. Q: Do the users easily understand the relation between the overview and the detail map (area, orientation) or not?

   A: Yes, for the majority of TPs.

3) Multi-path and time availability

a. Q: Do the users find multi-paths and free navigation better than following a single route or not?

   A: Yes, for the majority of the TPs.

b. Q: Is it easy for the users to find their way using multiple paths combined with landmark information or not?

   A: Yes, for the majority of the TPs. However, GPS inaccuracies posed several problems to that process.

c. Q: Do the users like the idea of multi-path routing alteration based on their time availability or not?

   A: Yes, for the majority of the TPs.

d. Q: Do the users like the appearance (colour / shape) of multi-paths on the map or do they prefer another way of displaying the same information?

   A: In general yes for the majority of them, but half of the TPs would prefer the shortest path to be always shown in a different colour, while several TPs suggested different colour coding of the paths based on specific characteristics of each path. Besides, several TPs suggest the reduction of the number of paths for little time availability to only one (the shortest path).

4) Landmark visibility

a. Q: Do the users find global landmark visibility information useful for orientation and navigation or not?

   A: Yes, for the majority of the TPs.

b. Q: Is the landmark visibility information accurate enough to let them relate correctly what they see in the surroundings to what they see on the mobile map?

   A: Partly, it is. There were problems with landmark visibility calculation accuracy as well as GPS and compass inaccuracies that made that not so easy in several cases. Getting used to that function was also slow for several TPs.

c. Q: Is the landmark visibility indication easily and correctly perceived by the users or do they prefer another solution for being shown that information?

A: In several cases the TPs did not understand the meaning of the colourful circle around the global landmarks. Generally they would need more time to get used to that function. Therefore, the solution should be redesigned to make it more easily perceivable and thus more usable.

5) Landmark pop-up information

a. Q: Do the users make use of the pop-up landmark information (photos + description text) and find it helpful to carry out their tasks successfully or not?

A: Yes, for the majority of the TPs.

b. Q: Would the users prefer an alternative way of being shown that or additional / different types of information?

A: For a third of the number of TPs, online landmark-specific information should be provided as well (for instance museum opening hours, entrance fees and so on).

c. Q: Do the users find the use of multiple-perspective photo selection based on their location and orientation better than single landmark photos or not?

A: Yes, for the majority of the TPs.

6) Landmark symbology

a. Q: Do the users easily understand the meaning of landmark symbols and icons / sketches or not?

A: Yes, for the majority of them.

b. Q: Do the users like the size and scaling of landmark icons / symbols / sketches in different zoom levels of the map or not?

A: Yes, for the majority of them. However, one third of the TPs complained about the crowdedness of the icons after performing several zooming-outs and they would prefer them to be smaller.

7) Scale bar and on-map compass

a. Q: Do the users find the movement of the scale bar position more useful (starting from the user's position) and its vertical orientation more useful than a standard fixed-position horizontal scale bar?

A: Yes, for the majority of the TPs.

b. Q: Do the users like the combination of distance and time needed in the scale bar or not? Do they make use of that combined information during the tasks?

A: Yes, for the majority of them.

c. Q: Do the users like the rotating compass and do they make use of it in order to orient themselves and navigate?

A: No, for the majority of them. However, as it was useful for one third of the TPs, the function should be available.

8) Interface interactivity

a. Q: Do the users easily understand the meaning of the on-screen buttons, their functions and their state (enabled / disabled) or not?

A: Yes, for the majority of the TPs.

b. Q: Is the response of the interface fast and convenient to the user input (taps on the map for landmark information retrieval, zooming-in and out / panning / button press response) or not?

A: Yes, for the majority of them.

9) Landmark filtering

a. Q: Is the filtering of landmarks on the mobile map based on the heading of the users and their selected destination helping them to orient themselves and navigate with more ease? Does this reduce their mental load or do they prefer having all the landmarks visible on the map at the same time at any instance?

A: Yes, for the majority of the TPs. However, as almost one third of the TPs either did find it a beneficial function or would like to disable it at particular times, a manually selectable override of the function should be available.

b. Q: Do the users like that the function of landmark filtering is off when the North-up map view is enabled and on when the rotated map view is enabled or not?

A: Yes, for the majority of the TPs. However, many of them did not make use of that during the tests because they were not familiar with the function. Therefore, a redesign of the solution is needed.

10) General impressions, problems and areas for improvement

a. Q: Do the users find LN in general more usable than existing applications that they have tried (e.g. Google Maps)?

   A: Yes, definitely.

b. Q: What are the problems that the users are confronted with during the use of LN reducing their orientation and navigation performance?

   A: Mainly GPS and compass inaccuracies but also icon overlapping in particular map zoom levels.

c. Q: What are the functions that could be improved in LN so that they meet their needs and expectations better?

   A: Mainly a richer database of landmarks, better accuracy for landmark visibility, reduction of icon cluttering, richer and more accurate pop-up information about landmarks, improved dual map solutions, further parameterization of landmark type presentation and more distinctive multi-path colour coding.

d. Q: Do the users get satisfaction from the use of LN and would they use it for future travels if it was possible to have coverage of the city of interest?

   A: Yes, for almost all of the TPs.

Based on the presented answers, it can be concluded that the LN prototype satisfies most of the usability requirements that were initially set and the applied solutions produced very good results measured in terms of efficiency, effectiveness and user satisfaction. Minor revisions to the interface following the proposed solutions of Section 6.4.3 could further increase its usability. This should be done in a next development / testing iteration, something that would exceed the aims and limitations of this research.

6.4 Conclusion

This chapter presented the procedure that was followed in order to test the usability of the prototype of LN. In this course, many issues regarding the aims, the preparation and the execution of an experiment which was done in the field involving 24 representative users of the interface were discussed. The research material resulting from the tests was a very valuable source of information which helped identifying the weak and strong points of the prototype design, in terms of efficiency, effectiveness and user satisfaction. To get full benefit of that material, in the form of audio and video recordings, verbatim transcription and coding was applied. In this way, different types of qualitative and quantitative data outlining the user experience with LN were extracted. Using those, the outcomes of the task-based user tests were then discussed in detail and different solutions for the improvement of the prototype were proposed. These solutions can be used as design guidelines for a future implementation and testing iteration of LN. The user testing experiment was executed without major problems with the equipment, the TPs or the methodology besides a delay of completion of the tests due to weather conditions and personal issues of the TPs.

In general, although the product of a single design and implementation iteration in the form of a LN prototype was tested, it demonstrated a decent amount of usability, noticeably better than GM. This was something that was identified and measured experimentally. In its current state, LN meets the majority of the design requirements which had been set initially. Although it could be further developed following the proposed usability improvement solutions, this is not necessary as the aim of this research is not the production of a market-ready interface. Instead, the focus was on the formulation of a sound methodological approach for the development of a usable mobile interface which would help pedestrians orient themselves and navigate in unfamiliar urban areas.

7. Conclusions and discussion

7.1 Overview

Geo-mobile applications are potential support tools for personal geo-identification in space (orientation) and navigation activities, especially in unfamiliar areas. However, the process of properly linking different sources of information, such as reality, mobile maps and the user's mental maps, needed for those activities is not yet well supported in currently available navigation systems. This research project tried to cope with that problem, investigating the specific requirements of pedestrian users of mobile navigation systems, and proposing new, usable ways to address them. In this regard, UCD was followed as a convenient methodology to design and test a prototype mobile interface which encompasses different new ideas and technical solutions.

In **Chapter 2** an overview of the current problems of geo-mobile applications was given and different proposed approaches to address them were described. It is apparent that an ample amount of research has been carried out on how to cartographically represent reality in small mobile screens, while keeping the intelligibility of the provided information high. Adapting this information according to the different contexts of use and users, properly scaling it and using special techniques to represent are the main research considerations.

To obtain a deeper insight into the current state of affairs in the field of geo-mobile applications, a comparative evaluation of different existing research projects was undertaken in **Chapter 3**. Most of those projects have outcomes in the form of prototypes and followed various methodologies for addressing their objectives. However, what has still not been given much attention is how users of geo-mobile applications link together different sources of information (i.e. mental maps, mobile maps and reality) and by what means the outcomes of such a study could contribute to developing more usable solutions for those users. In general, regardless of its importance, usability as an ultimate goal has been overlooked in many projects and a rather small number of them uses a structured user-focused research methodology to achieve it.

The novelty of this research lies in the combination of: (i) extracting the important and linked elements in the multiple information sources used for orientation and navigation by the users of geo-mobile applications and (ii) transforming the above results into a usable prototype mobile interface.

Chapter 4 provides a description of the UCD-based methodology selected for employing the objectives of this research project and an outline of its consecutive stages. Context of use and user as a crucial factor for understanding user interactions and needs was largely considered during the development of the research methodology. Therefore, already from the beginning, a task-based experiment designed to gather user requirements as part of the UCD-process was executed in the field with representative users and already existing geo-mobile applications. By doing so, it was possible to capture many details regarding user behaviour when orienting and navigating with the help of this type of applications that could have been missed in a laboratory setting. Being of a qualitative nature, the experiment was based on a combination of methods and techniques built upon the think aloud method. This decision was taken in view of the need to elicit not only the user actions in and reactions to different triggering events and decision points, but also the reasons behind those responses. The 8 test persons who were selected to participate based on specific criteria, such as unfamiliarity with the test areas, were asked to think aloud while orienting themselves and navigating to two sequential pre-selected destinations. The researcher was continuously triggering that thinking aloud, especially when the test persons seemed to have got confused or disoriented or when they were making important decisions. While executing the tasks thinking aloud, the test persons were video- and audio-recorded from different perspectives synchronously through a custom electronic field observation / recording system. After the end of the test sessions, the test persons were semi-structurally interviewed and audio-recorded to derive additional information from them and verify the researcher's observations during the task execution. They were also asked to draw a map of the route they followed during the experiment and its surroundings. This drawing was regarded as an abstract representation of their mental maps and their contents.

All the resulting research material from the requirement analysis experiment was analysed so that landmark types important for orientation and preferred map and landmark presentation forms were identified. Besides, the main reasons for users' spatial confusion and disorientation as well as a plethora of their problems, expectations and information requirements were discovered. Amongst other things, the test persons preferred to have unique icons for landmarks related to their types and functions and be able to get additional pictorial and text information about them through pop-up windows. This had to be supported by user-friendly, context-sensitive landmark selection and automatic map zooming techniques to minimize the use of the zooming function by the users.

The outcomes of the requirement analysis experiment laid the foundation for the conceptual design and prototype implementation of a more usable interface for mobile navigation, named LandNavin (LN) as presented in **Chapter 5**. The course of actions taken during that phase included use task analysis and interaction modelling. Using task analysis, four discrete tasks of orientation and navigation, presented in Figure 5.2 and the assigned user questions, information requirements and sources of trouble were distinguished.

Grounded on those, it was possible to schematize an optimal flow of interactions between the users of a usable mobile navigation system and the system's interface through use case modelling. System design requirements were then established and specific technical solutions, such as multi-path routing, landmark visibility information provision and reverse overview+detail maps were suggested to meet those requirements. It was considered to be important to describe in detail proposed ways of implementation of each of the technical solutions and determine possible issues that could affect their proper functioning. The prototype development environment, in this case Google Android Java running on Eclipse IDE for Windows, was selected on the basis of a series of criteria. For instance, the easiness of code development and the compatibility with mobile device platforms fully supporting the functionality of the designed prototype interface. At the end of Chapter 5, the prototype software development process is detailed and the actual implementations of the technical design solutions are illustrated. Together with those, particular issues that were addressed during that process, such as software crashes and landmark visibility calculation inaccuracies are reported.

Chapter 6 embodies the design, execution, problems and result analysis of the usability testing of the implemented LN prototype interface. The aim of the testing was to empirically assess the effectiveness, efficiency and user satisfaction provided by the interface and the accomplishment of user requirements as part of the followed UCD methodology. To capture the dynamic nature of the context of use while evaluating the prototype, field-based testing with 24 representative users was executed. During testing, each participant had to complete a series of tasks, with the overall goal of orienting him or herself and navigating to two given destinations with the help of an electronic navigation tool. Interchangeably using LN and Google Maps for those tasks was found to be a good solution for comparing the usability of the prototype to an existing, typical navigation interface. The test tasks were directly related to the ones defined in Chapter 5 and included sub-tasks which were evaluating, where possible, related parts and functions of the two interfaces. Two areas in Amsterdam, with diverse structural characteristics were selected for the tests.

Understanding the feelings and mental processes of the test persons behind their actions while executing tasks is very important for evaluating new design solutions. Therefore, thinking aloud as a method capable of extracting this information was given a central role in the usability evaluation methodology, together with observation and audio / video recording. At the end of each test session, a semi-structured interview was done to obtain additional qualitative data about the functionalities of the prototype from the test persons' perspective. To technically support this methodology, a new version of the field observation and recording system was built. Combining thinking aloud with eye-tracking techniques would hypothetically reveal even more details regarding the underlying mental processes and interactions of the users. However, a thorough evaluation of that idea failed to produce acceptable results due to accuracy and complexity issues. Two pilot tests to inspect the testing methodology and the involved technical equipment were executed. Through those, several issues were identified and modifications were made accordingly, to both software and hardware used.

In the second part of Chapter 6, the strategies for analysing the large amount of the resulting quantitative and qualitative usability testing research material are discussed. Different measurements of effectiveness, efficiency and user satisfaction for each task are presented and various design improvement solutions are denoted. In the end, each of the usability questions is answered on the basis of an analysis of the final outcomes.

7.2 Answering the research questions

In conclusion, the answers to each of the research questions set in Section 1.2 may be summarized as follows:

I. *Which elements of the environment, the mental maps associated with it, and the mobile cartographic interface do users of geo-mobile applications mainly use in order to orient themselves and navigate in space? Under what circumstances could they lose their mental connection with these sources?*

Those elements are: the local and global landmarks and their patterns, sequences and relations, as well as the routes related to landmarks, especially at decision points.

The users could lose their mental connection with the three sources of information mainly when: (i) the mobile map is not properly aligned to reality, (ii) the mobile map does not continuously show important landmarks in successive scales, (iii) not enough information is provided regarding nearby landmarks especially when they are related to route decision points, (iv) incorrect sizes and patterns of streets appear on the map, (v) the position arrow on the mobile map is inaccurate, (vi) there is no smooth transition between overview and detail maps.

II. *What are the main sources of distraction in the communication of geographic information through geo-mobile applications?*

On the small-sized displays of mobile devices it is very difficult to provide the users with overview and detail information at the same time, as is possible in case of paper maps. Repeatedly zooming-in and out and panning the mobile map in order to acquire this information is then needed. However, that complicates the mental interaction of the users with the geo-mobile application, often producing disorientation. That happens especially when the map transitions are not smooth or map contents are heavily generalized or disappear in different zoom levels.

The dynamic context of use of geo-mobile applications is another source of communication distraction, as the users are mostly on the go and use the application under disturbing conditions (environmental noise, weather changes, interruptions by other people and so on).

III. *What problems occur with current implementations of geo-mobile applications that have arisen from the outcomes of research or commercial projects?*

To begin with, there is still a lack of research on the user's mental interactions during mobile map use in real contexts. There is also no clear answer to the question what are the most usable forms of landmark representation on mobile maps depending on the context of use and the users' characteristics. Besides, context awareness of the applications is based on many different contextual parameters, but the user's profile and characteristics, although fundamental ones, are not oftentimes considered. Another problem is that in most of the cases the involvement of the users takes place only during the last phases of the projects, when an evaluation of an implemented prototype is needed. Clearly, user-centred design development methodologies, which would produce more usable results, were not followed by the majority of the executed projects.

IV. *What is a convenient research approach for compiling user requirements while keeping the need for human and technical resources low, and what possible issues need to be considered?*

Think aloud is a fundamental method to extract users' feelings, ideas and reasons behind actions. Combining it with pre-session questionnaires for user profiling, synchronized recording of thinking aloud, user actions and display screen logging, provides a very valuable source of information for eliciting user requirements. Post-session semi-structured interviews allow for verification, reviewing and better interpretation of the outcomes of the above combination of research methods and techniques.

Using a carefully designed wireless field observation / recording system, it was possible to successfully execute the requirements gathering experiment of this research project by a single researcher. As the experiment was done in real contexts of use, the collected research material revealed significant details which could not be captured in a laboratory setting. In addition to that combination of methods, mental map drawing was used, providing a further insight into the contents and structure of the test persons' cognitive maps. This was particularly beneficial for this research in which the users' multi-source linking when orienting themselves and navigating was the subject of investigation.

As it comes to the issues identified, thinking aloud is not always easy for the test persons and needs careful consideration by the researcher. During the requirement gathering and usability testing experiments of this research, the test persons several times stopped walking while trying to verbalize their thoughts. However, regardless that problem, thinking aloud provided very valuable results, notably in user disorientation and confusion instances.

V. What types of information are pedestrian users of geo-mobile applications initially seeking when trying to orient themselves in unfamiliar places?

They first identify their position by looking at the GPS position arrow on the mobile map. Then they try to align the contents of the map, such as street patterns and sizes to what they observe in reality in order to orient themselves.

VI. What types of important landmarks are there to help pedestrian users orient themselves and navigate in unfamiliar areas?

According to the results of the requirement gathering experiment, these are canals, bridges, pedestrian crossings, important buildings such as municipality offices, and global landmarks, visible from far distances. Additional landmarks are big shops, restaurants and fast food branches, churches, noticeable monuments and parks. However, the types of landmarks important for orientation and navigation depend to some extent on the area structure. For instance, canals are very useful and noticeable in Amsterdam centre, but their role is replaced by small parks or roundabouts in areas with not many easily distinguishable buildings.

VII. What type of map and what type of landmark presentation would pedestrian users of geo-mobile applications find most useful when orienting and navigating?

Most of the users prefer 2D instead of 3D maps, although they think that 3D models of buildings, if carefully selected and presented on the map could improve their mental connections with the mobile map and reality. Still, pop-up photos of landmarks are regarded as more helpful for orientation and navigation than 3D landmarks. The map should have visible continuous house numbering and street sizes and patterns directly related to reality, and should include railroads, building blocks and pedestrian paths.

VIII. *What are the main problems with which pedestrian users of geo-mobile applications are confronted when trying to link reality, mobile maps and their own mental maps?*

The absence of important landmark types from the mobile map or their non-continuous visibility in successive map zoom levels is one of the main problems for the users. Presenting the landmarks in not easily perceivable formats was another one. Furthermore, the use of the geo-mobile application alone interferes with the development of the users' mental map. This happens because the users often pay a lot of attention to the mobile map and their position / orientation on it in order to keep on the correct route and not lose their orientation. By doing so while moving, they miss several reference points in reality which would be otherwise stored in their memory successively in a spatially structured frame, forming their mental map of the area. Getting familiar with new areas is a process of cognitive mapping development and as such it should be preserved by geo-mobile applications, through a continuous provision of spatial cues that the user can easily identify in reality and memorise.

Lastly, the inaccuracies of the GPS position / direction arrow negatively affect the effort of the users to align the map with reality, using landmarks as reference points, especially in areas with low structural diversity. A clear preference towards a GPS-independent, continuous rotation of the map towards their point of view was identified.

IX. *Which are the main orientation and navigation tasks of pedestrian users of geo-mobile applications, and what related questions do they have?*

Through a task analysis done on the basis of the requirement analysis results and related usage scenarios, four main tasks were identified: The first task is Initial Geo-identification (orientation) and the related user questions are: "Where am I?" "What is around me?" "Where am I heading to?" The second task is Identification of Destination and Travel Decision and the related user questions are: "Where is the destination?" "How far is the destination?" "In which direction is the destination?" "Which route towards the destination is the most convenient?" The third task is Route Confirmation / Route Control / Reorientation and the related user questions are: "Am I on a correct route?" "Am I heading towards the correct direction?" The fourth task is Destination Confirmation and the related user question is: "Is this the correct destination?"

Besides these four main tasks, there is also a fifth, underlying task, that of actual navigation to the destination by physical movement of the user.

X. *What are the main information requirements of pedestrian users of geo-mobile applications that are related to the above tasks?*

The most essential requirements are an accurate user positioning, an interchangeable North-up and heading-up map (with compass-based rotation), panning and smooth zooming capabilities, a street map with patterns and sizes reflecting reality, a map scale indication, filtering of landmarks based on their visibility and their position (around current position, in the direction of the destination), multiple routing to the destination based on the user's decisions, clear and reach information about the destination (such as on-line landmark-specific details and suggestions) and legible symbology, naming and information for landmarks.

XI. *What type of (new) technical solutions would improve the ability of pedestrian users of geo-mobile applications to orient themselves and navigate?*

Following a UCD-based design and evaluation methodology in this research, five substantial technical solutions were developed and tested. The first solution is the use of an electronic compass sensor to continuously rotate the map towards the viewpoint of the user. The second solution is the provision of multi-path routing to the users, letting them freely decide which route to the destination is the most convenient for them. The multi-paths include any accessible pedestrian path between the position of the user and his or her destination, falling inside a pre-determined buffer related to the time availability of the user. The third solution is the indication of global landmark visibility, derived from real-time calculations, using landmark visibility layers. The fourth solution is the use of a reverse overview+detail map, where a detail map of the user's surrounding area is presented in a small window on the mobile screen and an overview map covers the remaining of it. The two views are clearly related to each other and independently zoomable and pannable. Finally, the fifth solution is the provision of landmark photos taken from different angles, depending on the orientation of the user towards that landmark. These multi-perspective photos are presented in the form of pop-up windows when the user is clicking on particular landmarks. The usability testing of the above technical solutions show a noticeable increase of the users' performance when orientating and navigating over earlier implementations.

XII. What is a suitable environment for developing a prototype mobile interface that encompasses the above technical solutions and what problems are likely to be encountered when doing so?

Google Android as a mobile device platform incorporates different sensors (GPS, compass, accelerometer) and supports open-source, Java-based software implementations. Besides, it allows for easy integration of applications with Google Maps API and offers programming support through a large coders' community. Combined with Eclipse IDE environment for Windows, Java for Android as a programming language is a powerful and easily-learned tool for developing software interfaces. The minimum technical characteristics of Google Android platform mobile devices, such as screen resolution, touch screen integration, and processing power also met the criteria set by this research for mobile device selection. Thus it was selected for the design and implementation of LN, the prototype interface of this research project.

XIII. What would be an efficient setup testing the usability of prototype interfaces of geo-mobile applications if time and resources are limited?

A field-based empirical testing technology, based on the think aloud method combined with observation, audio / video recording, screen logging and post-session interviews proved to be again a very convenient solution for the usability evaluation, producing a very rich research material and requiring very low human resources. Using an improved version of the field observation and recording system which was built for executing the requirements gathering experiment, better quality video and audio recordings were produced making the analysis of the resulting data easier.

XIV. Which prototype interface functions do users find useful, and which ones need to be improved or abandoned?

The heading-up map, the global landmark visibility indication, the time availability-related multi-paths, the popping-up landmark information, the multi-perspective photo provision, the movable scale bar and the landmark filtering were very well accepted by the test persons during the usability testing. In contrary, the on-map compass was not considered as important for the majority of the test persons. Minor improvements should be applied to the multi-paths by always highlighting the shortest path, to the landmark visibility indication by making it more distinguishable and to the landmark filtering by allowing for manually disabling the function. Moreover, the landmark icons should be smaller in all the zoom scales to avoid excessive cluttering and on-line information should be provided for landmarks of touristic interest. As it comes to the reverse overview+detail map, although it reduced the need for zooming-in / out for half of the test persons, it was regarded as too complicated. Therefore, it should be redesigned.

XV. How do users assess the usability of a prototype for meeting their objectives?

The analysis of the results indicate a considerably good amount of efficiency, effectiveness and user satisfaction in terms of task execution achieved with the use of LN and in comparison to Google Maps.

XVI. What are the problems and what are the benefits of the UCD-based approach followed for improving the usability of mobile cartographic interfaces?

In general, the followed methodology worked well and produced decent results. However, there are a few issues which should be considered in future similar studies. First, the difficulties to establish a test person population with demographics of large diversity limited the findings of this research to a more specific type of users. And second, the selection of a particular city (Amsterdam) for the user requirements gathering and usability testing somehow tied the context of use to specific characteristics of that city.

7.3 Recommendations for further research

During the realization of this research, a number of issues were encountered which could lead to some recommendations for future research. The experience with users and testing in the field revealed the need for reducing the influence of the researchers to the test persons to the minimum possible in order to have realistic results. Using a wireless field observation and recording system as the one built for this research was a sound approach towards that aim, as the researcher could keep a fair distance from the test persons letting them feel freer and behave more naturally while executing the given tasks. However, the test persons still know that there is someone nearby inspecting them and this reduces their natural impulsiveness. An idea to address this issue would be to implement an internet-based wireless observation system which would make it possible to remotely execute field-based user tests with a further reduced amount of bias from the researcher. The test persons could be given directions before the experiment and then let free to carry out the test tasks, producing more realistic results for the given context of use.

Landmark icon cluttering was one of the serious issues identified during the usability testing of LN, reducing the legibility of the map in areas where many landmarks existed but also when the user was using a map zoomed out very much. Therefore, a convenient solution should be investigated and applied, such as automatic icon placement and icon reduction based on well-defined rules in accordance with the user's preferences.

Given the limitations of this research, it was not possible to conduct continuous iteration cycles of design and development with users. However, earlier validations of simple prototypes of LN, even mock-ups, would have provided ample feedback for progressively designing a possibly more user-friendly interface. Heuristic evaluation also belongs to the methods that would benefit the development of LN if they were applied, as it would allow for discovering and eliminating different usability problems before the more advanced functions of LN were implemented. As the already established technical solutions in LN show a very good potential, more research is needed on how to provide these solutions to the users in a more intuitive and less complex way.

Another recommendation would be the execution of a research investigating the relation between the usability of geo-mobile applications and the screen size of the mobile device used. As recently a new category of mobile devices appeared in the market encompassing larger displays in the range of 7 to 9 inches and more processing power (e.g. Apple iPad, Samsung Galaxy Tab) it would be possible to execute such a study.

A technical solution that was considered as potentially usable but could not be materialized in this research due to implementation difficulties was the automatic recognition of landmarks. This solution would be different than what is already available in applications such as Layar (described in Section 5.5). Rather than using only the GPS and digital compass sensors to locate particular landmarks, the idea was to apply image recognition and pattern comparison techniques in order to directly recognize objects in reality when their image exists in a database. Combined with landmark visibility indication, this solution could provide the users with immediate references for orientation and navigation, dramatically reducing their mental load. Making use of the GPS position, digital compass and digital camera of the mobile device, a pattern recognition algorithm could determine which landmark is in the viewpoint of the user at any time. Then this landmark could be highlighted on the map and pop-up information could be shown automatically. Amongst the problems with this solution are the change of building colours during different times of the day and the change of the building size captured by the mobile camera depending on the distance from it.

The core idea of this research was the study of how the users of geo-mobile applications link reality with their mental maps and the mobile map when trying to orient and navigate. Based on the findings of this study, a more usable cartographic interface for pedestrian navigation systems should be implemented. Did that idea succeed in this research? Considering the results of the prototype evaluation, a usable design was created indeed, assuring that the methodology followed in this research met the initial research aims. However, more research is needed to confirm the findings but also test the possibilities of applying the same methodology in different contexts and domains.

As an overall conclusion, it can be stated that there is a large need for more user research in the geospatial domain. Technology provides the tools for developing countless solutions; however, what has to be developed further is to learn from the user and design for the user.

Appendix 1: Requirement analysis experiment pre-selection questionnaire

Participant identification number (to be filled–in by the researcher): ___________

Introduction

This questionnaire aims at collecting (anonymous) information regarding the general profile of each participant as a user of geo-mobile applications and a visitor to the city of Amsterdam in order to help the analysis of the results after the completion of the tests.

Every participant gets an identification number (TP1, TP2, TP3 and so on) and no personal information will be made public when reporting the research. Please answer all questions and do not hesitate to ask for the help of the researcher when a question is in the questionnaire is not clear.

Questions

1. Please indicate / tick:
   a. Your age: ______
   b. Your gender: __ male __ female
   c. Your Country of origin:

      ____

   d. Your profession:

      ____

   e. Your studies field(s):

      ____

      ____

2. What is the size of the settlement in which you are living / working? Please indicate

   ____

   ____

3. How often do you travel to unfamiliar cities / areas of cities? Please indicate

   ____

   ____

4. How long have you been in the Netherlands? Please indicate

   ____

5. Do you have knowledge of GPS systems?

   __ No __ Poor __ Modest __ Very good

6. Do you have practical experience with GPS systems?

__ No __ Poor __ Modest __ Very good

7. Do you have practical experience using digital maps?

__ No __ Poor __ Modest __ Very good

8. Do you have practical experience using PDA devices?

__ No __ Poor __ Modest __ Very good

9. Do you have experience with mobile navigation applications?

__ No __ Poor __ Modest __ Very good

10. Are you (practically) familiar with any of the following applications?

Nr.	Application	Familiarity (tick)
1	agis Navigator	
2	Alturion GPS Professional v.6.0	
3	amAze	
4	Co-Pilot Live v.7.0	
5	Destinator 7.0	
6	Google (mobile) Maps	
8	Nav N GO iGo My way 2006 plus	
9	Nav N GO iGo My way v.8.0	
10	INav i-Guidance v.4.0	
11	Intellinav v.2.0	
12	Maptech Memory Map v.5.0	
13	Marco Polo Mobile Navigator 3	
14	MioMap v.3.0	
15	MioMap 2008	
16	Navigon Mobile Navigator v.6.0	
17	Nokia Smart2Go	
18	Odyssey Mobile	
19	onCourse Navigator v.6.0 Plus	
20	Pharos Ostia	
21	PocketMap Navigator (USA)	
22	PocketWAW22	
23	Route 66 v.7.0	
24	Teletype GPS	
25	Tom Tom Navigator v.6.0	
26	Via Michelin	

11. Have you ever been in the city of Amsterdam?

__ Yes __ No

12. Have you ever been to the places that we are going to do the test?

__ Yes __ No

13. Did you prepare for today's visit (e.g. by looking at tourist websites or by looking at map displays of Amsterdam)?

    __ Yes __ No

14. Do you usually prepare yourself before to go to an unfamiliar to you city / area in order to prevent getting lost there?

    __ Always __ Frequently __ Sometimes __ Never

15. If you did not answer "Never" in the previous question, what are your usual preparation activities? Please indicate:

    ____

    ____

    ____

16. When you go to an unfamiliar city / city area with a group of friends are you the one who takes responsibility for orientation and navigation?

    __ Always __ Frequently __ Sometimes __ Never

17. How often do you use paper maps when traveling to a place that you are not familiar with?

    __ Always __ Frequently __ Sometimes __ Never

18. Do you have difficulties to orient yourself when you are arriving in an unfamiliar to you city / area when you use a paper map?

    __ Always __ Frequently __ Sometimes __ Never

19. How often do you use mobile navigators when you are traveling to a place that you are not familiar with?

    __ Always __ Frequently __ Sometimes __ Never

20. When you are visiting an unfamiliar city / city area do you perform any type of acts in order to help yourself understand the place better and be able to go around and not get lost? If yes, please indicate:

    ____

    ____

    ____

21. When you suddenly realize that you have lost your way or you don't know anymore where you are in an unfamiliar city / city area what your instant acts are in order to solve the problem? Please indicate:

    ____

    ____

    ____

22. When you are going to a city / place for a second time, supposed that this happens after relatively short time, are your abilities to orient yourself and navigate there improved?

    __ Yes __ No

23. If you answered "Yes" in the previous question, please indicate what you think that is / are the reasons for that:

    ____

    ____

    ____

24. Please draw your mental map of Enschede

Thank you very much for your time and consideration.

Your participation is much appreciated.

Appendix 2: Requirement analysis experiment literal instructions

1. General remarks about the experiment

This research has the aim of studying how people orient themselves and navigate in an unfamiliar area with the help of geo-mobile applications. In particular, looking at the relationship and interaction between reality, representation of reality through a map display on the mobile device and the user's mental maps. Using two existing geo-mobile applications, Nav N GO iGo My way v.8.0 and Google Mobile Maps, the above aspects are investigated.

There is no intention to judge the participants themselves in terms of orientation and navigation abilities.

The participants generally resemble visitors to an unfamiliar city.

Amsterdam is selected as test area and the transportation to it takes place by train for three reasons. First, Amsterdam is visited by many people (e.g. tourists) who have not been there before and they often go there by public transport. Second, the train trip allows for interaction between the researcher and the participants in order to prepare the latter for the experiment and acquire some important research data from him or her through a questionnaire and mental map drawings. Third, the Municipality of Amsterdam (Dienst Stadstoezicht) takes part in the RGI research project Usable (and Well-scaled) Mobile Maps for Consumers (UWSM2), to which this experiment makes a contribution as well. The bonus for the test persons is that they are offered a free ride to Amsterdam where they may spend the rest of the day as they like.

Due to time and resource limitations each trip to the testing area is made by two participants at the same time. However, they execute the test independently.

The two test persons and the researcher will travel together from Enschede to Amsterdam Central Station. When the first participant and the researcher will go to the first of the two selected test areas (Metro Station Wibautstraat / Amstel Station), the second participant will first have one and a half hour of free time. An appointment with him or her and the researcher will be set during the train ride. The meeting point is the VVV Tourist Office, just outside and across Amsterdam Central Station. The researcher will come there with the first participant by metro, after having completed the first series of tasks.

You should be very aware of possible robbers and pickpockets in the centre of Amsterdam. So, you should put any valuable things (wallets etc.) in safe places under your clothes.

After completion of the test, the first test person is free to go where he or she likes for the rest of the day. The same holds for the second test person after completion of his or her test.

2. Briefing instructions

This research makes use of electronic equipment during the test execution. The devices used are a 4-channel digital video / audio recorder, 3 high resolution colour cameras, 2 set of video transceivers, a DECT phone-based wireless audio communication through headsets, a Windows Mobile-based PDA with video-out connector and two geo-mobile applications installed and two sets of high capacity Lithium battery clusters. The current technical configuration is an improved version of the field observation system used in my MSc Research. It allows for remote observation and audio / video recording of the test persons. You will be shown a movie from that research in order to have a first idea of the aims and capabilities of such systems and what types of information can be collected.

As a first step, both of you will be asked to complete a questionnaire (see Appendix B). This questionnaire aims to create an (anonymous) general profile of you as a user of geo-mobile applications and a visitor to the city of Amsterdam. Every participant gets an identification number (TP1, TP2, TP3 and so on) and no personal information will be made public when reporting the research. Please answer all questions and do not hesitate to ask for the help of the researcher when a question is in the questionnaire is not clear.

After finishing the questionnaire, you will be asked to draw on a blank A4 page a map of your hometown in Netherlands, which is in this case Enschede. You should draw a sketch based on the map that you have in your mind about this city and include anything that you find important. The location of ITC, your residence and the usual route(s) that you take every day to walk / bike to ITC should be visible as well. During the execution of this task test persons should not interact with each other, nor look at each other's drawings.

After finishing drawing your mental map of Enschede, both of you will be given one mobile device, the same as the one that will be used for the experiment: an IPAQ hx4700 PDA running Windows Mobile 6.1. There are two applications installed with which you will have to become familiar as they will be used later in the field: Google Mobile Maps (running offline under Google Navigator software) and Nav N GO iGo My way v.8.0. You will be introduced to each of them and learn about the functions that may be used in the test.

Among the basic functions that you must learn are zooming-in / out and panning of the map presented. You will first do this with Google Mobile Maps. In order to do this, you will be shown a map of the city of Arnhem, where the whole city area is fitting in the screen, and what you have to do is to find the city of Apeldoorn and then try to zoom in to the center of this city (Apeldoorn) so that the widened canal in its centre together with the "Deventerstraat" bridge are visible. In order to do that, you should zoom out and pan to the north (up) first, and then zoom in and pan until you centre the required area in the screen. After that you should again find Arnhem and try to zoom into one of the two roads that pass over the big canal passing close to the centre of the city. The name of the bridge is "Nelson Mandelabrug". In order to do that, you should first zoom out and pan to the South (down) and then zoom in and pan until you centre the required area in the screen. During this task you should not have visual contact with the map screen of the PDA of the other test person.

After this, the GPS receiver will be turned on and you will be able to see how the software acts during real navigation conditions (train movement) and you will have some time (around 5 minutes) to play with the functions of zooming and panning and understand better how the software works.

The same tasks as above will be repeated using iGo My way v.8.0 this time.

In iGo My way v.8.0 besides zooming-in / out and panning there is also the possibility to view the map in 2D and 3D mode. In the 3D mode 3D models of city buildings can be visible on the map. During the train trip and with the GPS receiver on, you will get an idea of all the possible modes that can be used. You should decide which mode is more convenient for you to use at the start of the real tasks execution later on, although the modes can be changed afterwards all the time.

In iGo My way v.8.0 you should also learn how to add points of interest to the map (especially on your current position) as you will be asked to do so during the task execution later on as well.

3. Execution instructions for the test in the area Metro Station Wibautstraat – Krugerplein - Amstelstation

The main tasks to be executed during the actual test in Amsterdam will be the navigation to two points that will be given when the test starts. For half of the participants, the navigation to the first point should be done using Google Mobile Maps software and the second using iGo My way v.8.0. For the other half, the navigation will be done the other way round. Both the target points will be visible on the map as coloured dots (Google Maps) or pinpoints (iGo My way v.8.0). When starting each task, the map view zoom will be set by the researcher to show both the origin and the destination. You can plan any route that you think that is the best for you to navigate to each point. You are not supposed to make use of the route planning function of the geo-mobile applications. You can always use the zooming functions in order to get detailed or overview information that will help you during the navigation.

You should always try to think aloud and express any thought, feeling, idea about the orientation and navigation process, the map, the environment around you and any difficulties/solutions that you face. If you forget to do that for some time (more than 30 seconds) or if it is obvious that you are at a critical point (such as deciding to which direction to go, trying to find a particular sign that can help you navigating or you look confused with something), the researcher will remind you to express your inner thoughts.

The test starts when we exit Metro Station Wibautstraat. All the electronic equipment for the testing will be prepared and researcher and test person will put on the required devices (hat with cameras, backpack with the recorder / batteries / video and audio transceivers, and so on).

I will be following you in a distance of around 20 meters, and we will communicate wirelessly, through the headsets. You should not search for me and try to talk to me face to face except there is an important reason to do that (for example a serious hardware / software problem that you have).

The first task that you should complete is to navigate to target point 1 (Krugerplein) from Metro Station Wibautstraat. Both the origin and the destination will be visible in the map, as well as target point 2 (Amstelstation), the destination of the second stage.

When we are outside the Metro Station you will be asked to look around you, look at the map display on the mobile screen and the surroundings and try to answer the question “Where am I?” and after that, the question “Towards which direction should I move in order to reach my destination?” You are supposed NOT to use any street name signs during your orientation. Please try to find other things around you and in the map that can help you orient yourself. During this task you will be asked to think aloud regarding your thoughts / decisions / conclusions as this type of information is very important for this research.

You should try to find the shortest route to navigate to the target point 1.

During the task execution, if iGo My way v.8.0 is used, you will be asked to insert in the map the locations of a few parking machines (at least two) that you find on your way to the destination point. Do not forget to think aloud continuously and use the already mentioned functions of the software as they can help you navigate more easily.

You will have a discrete time limit to navigate to the target point 1. In case you reach that limit, we will move to the target and start the second navigation task.

Somewhere during your task execution, you will be asked to estimate the percentage of the trip that you have completed and how far you still have to go.

When you (we) reach the first target point, we will make a short break of around 3 minutes in order to change the software. Then you will again be shown a map view including the starting point (current - Krugerplein) and target point no. 2 (Amstelstation).

The second task that you should complete is to navigate to target point 2. Both the origin and the destination will be visible in the map.

You should try to find the shortest route to the target.

During the task execution, if iGo My way v.8.0 is used, you will be asked to insert in the map the locations of a few parking machines (at least two) that you find on your way to the destination point. Do not forget to think aloud continuously and use the already mentioned functions of the software as they can help you navigate more easily.

Somewhere during your task execution, you will be asked to estimate the percentage of the trip that you have completed and how far you still have to go.

When you reach target point 2 or the predefined time limit for this task, we will stop and put out / pack all the equipment. We will then take the Metro to go to Amsterdam Central Station again. Before and during this short trip you will be asked to draw on a blank A4 page a mental map showing the route that you followed in order to navigate to the two target points, including anything that you remember to exist in the environment where you passed through.

The last part of this session is a short semi-structured interview in retrospect based on some predefined questions (see appendix C) regarding the execution of the test (points of confusion, changes of direction, long stops in particular points and so on).

After we reach Amsterdam Central Station, you are free to spend the rest of your day in Amsterdam as you like.

4. Execution instructions for the test in the centre of Amsterdam (Dam Square – Begijnhof – Rembrandt House)

The main tasks to be executed during the actual test in Amsterdam will be the navigation to two points that will be given when the test starts. For half of the participants, the navigation to the first point should be done using Google Mobile Maps software and the second using iGo My way v.8.0. For the other half, the navigation will be done the other way round. Both the target points will be visible on the map as coloured dots (Google Maps) or pinpoints (iGo My way v.8.0). When starting each task, the map view zoom will be set by the researcher to show both the origin and the destination. You can plan any route that you think that is the best for you to navigate to each point. You are not supposed to make use of the route planning function of the geo-mobile applications. You can always use the zooming functions in order to get detailed or overview information that will help you during the navigation.

You should always try to think aloud and express any thought, feeling, idea about the orientation and navigation process, the map, the environment around you and any difficulties / solutions that you face. If you forget to do that for some time (more than 30 seconds) or if it is obvious that you are at a critical point (such as deciding to which direction to go, trying to find a particular sign that can help you navigating or you look confused with something), the researcher will remind you to express your inner thoughts.

The test starts when we reach Dam Square walking from Amsterdam Central Station. Before we walk there, all the electronic equipment for the testing will be prepared and the researcher and test person will put on the required devices (hat with cameras, backpack with the recorder / batteries / video and audio transceivers, and so on).

I will be following you in a distance of around 20 meters, and we will communicate wirelessly, through the headsets. You should not search for me and try to talk to me face to face except there is an important reason to do that (for example a serious hardware / software problem that you have).

The first task that you should complete is to navigate to target point 1 (Begijnhof) from Dam Square. Both the origin and the destination will be visible in the map, as well as target point 2, the destination of the second stage.

When we are in the middle of Dam Square you will be asked to look around you, look at the map display on the mobile screen and the surroundings and try to answer the question "Where am I?" and after that, the question "Towards which direction should I move in order to reach my destination?" You are supposed NOT to use any street name signs during your orientation. Please try to find other things around you and in the map that can help you orient yourself. During this task you will be asked to think aloud regarding your thoughts / decisions / conclusions as this type of information is very important for this research.

You should try to find the shortest route to navigate to the target point 1.

During the task execution, if iGo My way v.8.0 is used, you will be asked to insert in the map the locations of a few parking machines (at least two) that you find on your way to the destination point. Do not forget to think aloud continuously and use the already mentioned functions of the software as they can help you navigate more easily

You will have a discrete time limit to navigate to the first target point 1. In case you reach that limit, we will move to the target and start the second navigation task.

Somewhere during your task execution, you will be asked to estimate the percentage of the trip that you have completed and how far you still have to go.

When you (we) reach the first target point, we will make a short brake of around 3 minutes in order to change the software. Then you will again be shown a map view including the starting point (current - Begijnhof) and target point no. 2 (Rembrandt House).

The second task that you should complete is to navigate to target point 2. Both the origin and the destination will be visible in the map.

You should try to find the shortest route to the target point 2.

During the task execution, if iGo My way v.8.0 is used, you will be asked to insert in the map the locations of a few parking machines (at least two) that you find on your way to the destination point. Do not forget to think aloud continuously and use the already mentioned functions of the software as they can help you navigate more easily.

Somewhere during your task execution, you will be asked to estimate the percentage of the trip that you have completed and how far you still have to go.

When you reach target point 2 or the predefined time limit for this task, we will stop and put out / pack all the equipment. Then you will be asked to draw on a blank A4 page a mental map showing the route that you followed in order to navigate to the two target points, including anything that you remember to exist in the environment where you passed through.

The last part of this session is a short semi-structured interview in retrospect based on some predefined questions (see appendix C) regarding the execution of the test (points of confusion, changes of direction, long stops in particular points and so on).

After that you are free to spend the rest of your day in Amsterdam as you like.

Appendix 3: Requirement analysis interview questions

Participant identification number (to be filled–in by the researcher): ___________

Introduction

This interview aims at collecting additional (anonymous) information regarding the interaction between reality, mobile maps and mental maps of the participants, after they have completed the tasks of the test. Every participant gets an identification number (TP1, TP2, TP3 and so on) and no personal information will be made public when reporting the research. Audio recording of the conversation can be used if they don't mind, in order to make the analysis of the collected information easier. Otherwise written notes will be taken.

Questions

1. What are your general remarks regarding navigation with the use of each of the two geo-mobile applications based on the tasks that you had to execute?
2. Tell me more about each application. What do you think are their strongest points and which are their weakest ones? What was missing from them and could be improved to help you orient yourself and navigate with more easiness?
3. Is there any difference in the way each application is zooming-in and out as it comes to graphic representation?
4. What is more difficult: To keep an overview map of the area in your mind while you are zooming-in to see more detailed information or to keep in your mind the detailed information of higher zoom levels while you are inspecting an overview map of an area? Is frequent zoom level changing needed in order to maintain both overview and detailed map information in your mind?
5. What do you think should be included in the map in order to decrease the need for frequent zooming-in / out?
6. Imagine that in the middle of your route the mobile device / geo-mobile application stops responding. Do you think that you would still be able to reach your target without asking the help of other people? What do you think that could be in that case your main navigation support source?
7. What types of landmarks do you think that helped you orient yourself and navigate in each task?
8. What types of landmarks that existed along the route and could help you orient yourself and navigate were not available on the map display making your task execution more difficult?

9. What types of landmarks you generally expect to meet in your way that can help you find your way back when you are in an unfamiliar city?
10. Could you tell me when and where you found it more problematic to orient yourself and navigate?
11. What do you find as advantages and disadvantages of the 2D and 3D map representations in the present applications for orientation and navigation? Do you find the 3D building models useful? To what extend you believe they should be included in a mobile map display?
12. What are your general impressions regarding the experiment? Knowing the aims of this research, what do you think that could still be improved in the test setting?
13. Any additional comments / suggestions / ideas?

Appendix 4: Prototype usability testing pre-selection questionnaire

Dear candidate participant,

My name is Ioannis Delikostidis and I am currently doing my PhD at ITC, University of Twente. The subject of my research is improving the usability of mobile applications for pedestrian navigation. I am currently working on the usability testing part of my research, after having developed a prototype mobile navigation interface based on a User-Cantered Design approach.

I am asking for your kind contribution to my usability testing which will provide me with valuable feedback that will help me identifying possible issues in my implementation and solutions to improve its usability.

Through this questionnaire, I intend to select test persons with characteristics that fit in the profile of the target group population of my prototype. If selected, you will be given a series of orientation and navigation tasks to complete in one of two pre-selected areas in Amsterdam with the help of a mobile navigation interface. The transportation to the test area will be done by train and you will be given a return ticket to Amsterdam for free. After the completion of the test session, which will last 1 hour and 30 minutes at maximum, you are free to spend your day in that city as you like. The briefing and training will take place during the transportation from Enschede to Amsterdam or, in case we meet there, in a café close to Amsterdam Central Station. To carry out the tests, I will use a research methodology consisting of thinking aloud, observation together with audio / video recording and an interview.

All the information provided in this questionnaire will be strictly kept private and any reference to the test persons will be done later using codes (TP1, TP2, TP3 and so on) and not their real names.

Each test person can participate only one time in the test.

Please answer the following questions:

- What is your name and surname?

  ____

- What is your occupation or subject of studies now?

  ____

- What is your past studies field?

  ____

- Which age group do you fit in?

  ☐ 18-24 ☐ 25-30 ☐ 31-40 ☐ 41-50 ☐ 51-60

- What is your gender?

  ☐ Male ☐ Female

- For how long have you been in the Netherlands?

☐ Less than 1 year ☐ 1 year to 5 years ☐ More than 5 years

- How often did you travel to new places in the last 3 years?

  ☐ Once in a year or less ☐ 2-3 times per year ☐ Once every 3 months or more

- How many times have you been in Amsterdam?

  ☐ 0 ☐ 1 ☐ 2 ☐ 3 or more

- If you answered yes in the question before this, when was the last time that you visited Amsterdam?

  ☐ <1 month ago ☐ 1 month – 3 months ☐ 3 months – 1 year ☐ More than 1 year

- Are you familiar with the central area of Amsterdam?

  ☐ No ☐ Yes

- Please rank your ability to memorize places that you have visited recently:

  ☐ Poor ☐ Fair ☐ Good ☐ Excellent

- What is your experience with paper maps?

  ☐ None ☐ Poor ☐ Fair ☐ Good ☐ Excellent

- What is your experience with digital maps?

  ☐ None ☐ Poor ☐ Fair ☐ Good ☐ Excellent

- Please rank your abilities to orient yourself and navigate with the help of a map in places that you visit for the first time:

  ☐ Poor ☐ Fair ☐ Good ☐ Excellent

- Please rank your abilities to orient yourself and navigate in places that you have visited before (recently):

  ☐ Poor ☐ Fair ☐ Good ☐ Excellent

- What is your experience with GPS systems?

  ☐ None ☐ Poor ☐ Fair ☐ Good ☐ Excellent

- What is your experience with mobile navigation systems?

  ☐ None ☐ Poor ☐ Fair ☐ Good ☐ Excellent

- What is your experience with smartphones (touch screen etc.)?

  ☐ None ☐ Poor ☐ Fair ☐ Good ☐ Excellent

- What is your experience with Google Maps on mobile phones / PDAs?

  ☐ None ☐ Poor ☐ Fair ☐ Good ☐ Excellent

- Do you have any experience with any other navigation software for smartphones / PDAs?

  ☐ No ☐ Yes

- If you answered yes in the previous question, please name the software:

  ____

- How often do you use paper maps when you visit new places?

  ☐ Never ☐ Sometimes ☐ Frequently ☐ Always

- How often do you use mobile navigation systems when you visit new places?

  ☐ Never ☐ Sometimes ☐ Frequently ☐ Always

Thank you very much in advance for your time and consideration.

Your participation is much appreciated.

Kind regards,

Ioannis Delikostidis

Appendix 5: Prototype usability testing literal instructions

General remarks about the experiment

1. This experiment has the aim of assessing the usability of the first prototype of LandNavin, a mobile navigation interface for pedestrian navigation in unfamiliar cities / city areas. Together with LandNavin, Google Maps is also used for carrying out part of the test sessions. This is done for comparison reasons.
2. There is no intention to judge the participants themselves in terms of orientation and navigation abilities.
3. The participants generally resemble visitors to an unfamiliar city.
4. Amsterdam is selected as test area and the transportation to it takes place by train for three reasons. First, Amsterdam is visited by many people (e.g. tourists) who have not been there before and they often go there by public transport. Second, the train trip allows for interaction between the researcher and the participants in order to prepare the latter for the experiment and get familiar with the navigation interfaces and their functionalities. Third, an important type of 3D data used by LandNavin was only possible to be acquired for the area of Amsterdam. The bonus for the test persons is that they are offered a free ride to Amsterdam where they may spend the rest of the day as they like. It is possible that one or two more test persons participate in the experiment at the same day due to time and resource limitations. In that case, they come alone to Amsterdam by train (again using free return tickets offered) and the training is taking place in a café near Amsterdam's Central Station.
5. Due to time and resource limitations each trip to the testing area in the company of the researcher is made by two participants at the same time. However, they execute the test independently.
6. The (first) two test persons and the researcher will travel together from Enschede to Amsterdam Central Station. When the first participant and the researcher will go to the first of the two selected test areas (Metro Station Wibautstraat / Amstel Station), the second participant will first have one and a half hour of free time. An appointment with him or her and the researcher will be set during the train ride. The meeting point is the VVV Tourist Office, just outside and across Amsterdam Central Station. The researcher will come there with the first participant by bus, after having completed the first series of tasks.
7. In case of more than two participants in a day, an appointment with the third test person is set the day before the experiment at a time when both the first two test persons should have completed their sessions. The same applies to a fourth test person, with the appointment set at a time when the third participant should have completed his or her session. This implies that the third and fourth test persons travel alone to Amsterdam with a time difference of 1.5 to 2 hours. The meeting point for each of them is again VVV Tourist Office, just outside and across Amsterdam Central Station.
8. You should be very aware of possible robbers and pickpockets in the centre of Amsterdam. So, you should put any valuable things (wallets etc.) in safe places under your clothes.
9. After completion of the test, the first test person is free to go where he or she likes for the rest of the day. The same holds for the second, third and fourth (if available) test persons after completion of their test.

Briefing instructions

1. This research makes use of electronic equipment during the test execution. The devices used are a 4-channel digital video / audio recorder, 3 high resolution colour cameras, 2 sets of video transceivers, a DECT phone-based wireless audio communication through headsets, an Android-based smartphone with video-out connector and two sets of high capacity Lithium battery clusters. This field observation system allows for remote observation and audio / video recording of the test persons. You will be shown a movie of similar research in order to have a first idea of the aims and capabilities of such systems and what types of information can be collected.
2. To start with, you will be given a Samsung Galaxy S Android-based smartphone, the same as the one used for the test with two navigation interfaces installed (LandNavin and Google Maps). You will be introduced to each of them and learn about the functions that may be used in the test.
3. You will first be asked to make use of the basic functions of zooming and panning. You will use the zoom controls in order to see the map from street level to country-wide view. Then you will be asked to pan the map from the current position to the city of Enschede and back. The device has an integrated GPS receiver that allows your current position and movement to be shown on the maps so that you can have an interaction with the device under dynamic conditions. You will then learn how you can return to your current position on the map after you pan the map. You will be given 5 minutes to become familiar with these functions.
4. The next step is to learn how to change the map from road view to satellite view and how to select a destination that the interface will provide you with routing information to go to. The time availability option is only available in LandNavin and you will learn about it. You will also have a look at how the scale of the map is presented. This step will last for 5 minutes.
5. The same tasks as above will be repeated using both LandNavin and Google Maps (20 minutes in total).
6. Besides the functions described above, LandNavin has some additional ones which is the reverse overview+detail (or dual map), the rotated map towards your heading, the provision of visibility information regarding global (tall) landmarks and the provision of multi-perspective photos of the landmarks depending on your position and heading. An explanation of how these functions work will be given to you for 5 minutes.
7. You will have another 5 minutes to ask additional questions regarding both of the navigation interfaces in order to understand better their functions and capabilities.
8. The total time needed for the briefing is following the above schedule around 30 minutes in total.

Execution instructions for the test in the area Metro Station Wibautstraat – Albert Heijn in Krugerplein – café Dauphine in Amstelstation

1. The main tasks to be executed during the actual test in Amsterdam will be the navigation to two points that will be given when the test starts (the first point) and when you reach the first point (the second point). For half of the participants, the navigation to the first point should be done using Google Mobile Maps software and the second using LandNavin. For the other half, the navigation will be done the other way round. Both the target points will be visible on the map as pinpoints. After that, you will be given a series of orientation and navigation tasks involving understanding your position and heading at any time, finding and recognizing

landmarks around you, gathering information about them, following a provided route or one of the provided routes to reach your destination, using different functions of the interfaces and so on.

2. You can always use the zooming functions and panning functions in order to get detailed or / and overview information that will help you during the navigation, and use different map view types as desired.

3. The researcher will trigger you to think aloud and express your thoughts, feelings and ideas about the tasks you execute and especially regarding your findings during task execution, the interface response and any difficulties that you face.

4. The test starts when we exit Metro Station Wibautstraat after we go there by bus from Amsterdam Central Station. All the electronic equipment for the testing will be prepared and we both will put on the required devices (hat with cameras, backpack with the recorder / batteries / video and audio transceivers, and so on).

5. I will be following you at a distance of around 20 meters, and we will communicate wirelessly, through the headsets. You should not search for me and try to talk to me face to face except when there is an important reason to do that (for example a serious hardware / software problem that you have).

6. The first main task that you should complete is to orient yourself and then navigate to the first Destination (Albert Heijn in Krugerplein) from Metro Station Wibautstraat. You can easily make both the origin and the destination to visible in the map. During that main task a series of smaller orientation and navigation tasks will be given to you through printed paper cards.

7. You will have a discrete time limit to navigate to the target point 1. In case you reach that limit, we will move to the first destination and start the second main task (orientation and navigation to destination 2 (Café Dauphine in Amstel Station).

8. When you (we) reach the first target point, we will make a short break of around 3 minutes in order to change the software. Then you will start the second main task of orienting and navigating to destination 2 which again includes a series of smaller tasks to be completed.

9. When you reach destination 2 or the predefined time limit for this task, we will stop and put out / pack all the equipment.

10. The last part of this test is a short semi-structured interview based on some predefined questions (see Appendix 3) as well as some test person-specific questions based on important details of your task execution process.

11. We will then take the bus to go to Amsterdam Central Station again.

12. After we reach Amsterdam Central Station, you are free to spend the rest of your day in Amsterdam as you like.

Execution instructions for the test in the centre of Amsterdam (Dam Square – Bijbels Museum – De Doelenzaal theatre)

1. The main tasks to be executed during the actual test in Amsterdam will be the navigation to two points that will be given when the test starts (the first point) and when you reach the first point (the second point). For half of the participants, the navigation to the first point should be done using Google Mobile Maps software and the second using LandNavin. For the other half, the navigation will be done the other way round. Both the target points will be visible on the

map as pinpoints. After that, you will be given a series of orientation and navigation tasks involving understanding your position and heading at any time, finding and recognizing landmarks around you, gathering information about them, following a provided route or one of the provided routes to reach your destination, using different functions of the interfaces and so on.

2. You can always use the zooming functions and panning functions in order to get detailed or / and overview information that will help you during the navigation, and use different map view types as desired.

3. The researcher will trigger you to think aloud and express your thoughts, feelings and ideas about the tasks you execute and especially regarding your findings during task execution, the interface response and any difficulties that you face.

4. The test starts when we reach Dam Square walking from Amsterdam Central Station. When we reach that point, all the electronic equipment for the testing will be prepared and we both will put on the required devices (hat with cameras, backpack with the recorder / batteries / video and audio transceivers, and so on).

5. I will be following you at a distance of around 20 meters, and we will communicate wirelessly, through the headsets. You should not search for me and try to talk to me face to face except when there is an important reason to do that (for example a serious hardware / software problem that you have).

6. The first main task that you should complete is to orient yourself and then navigate to the first Destination (Bijbels Museum) from Dam Square. You can easily make both the origin and the destination to be visible in the map. During that main task a series of smaller orientation and navigation tasks will be given to you trough printed paper cards.

7. You will have a discrete time limit to navigate to the target point 1. In case you reach that limit, we will move to the first destination and start the second main task (orientation and navigation to destination 2 (De Doelenzaal Theatre).

8. When you (we) reach the first target point, we will make a short break of around 3 minutes in order to change the software. Then you will start the second main task of orienting and navigating to destination 2 which again includes a series of smaller tasks to be completed.

9. When you reach destination 2 or the predefined time limit for this task, we will stop and put out / pack all the equipment.

10. The last part of this test is a short semi-structured interview based on some predefined questions (see Appendix 3) as well as some test person-specific questions based on important details of your task execution process. After that you are free to spend the rest of your day in Amsterdam as you like.

Appendix 6: Prototype usability testing interview questions

Participant identification number (to be filled–in by the researcher): ___________

Introduction

The aim of this interview is to collect additional feedback regarding the usability of LandNavin from the test persons, after they have completed the usability testing sessions. Every participant gets an identification number (TP1, TP2, TP3 and so on) and no personal information will be made public when reporting about the research. Audio recording of the conversation will used in order to make the analysis of the collected information easier. If the test person disagrees with that, written notes will be taken.

Questions

1. What are your general remarks regarding navigation with the use of LandNavin alone and in comparison to Google Maps?
2. Which of the two routes do you remember better in terms of the surroundings along the route? What do you think is the reason for that?
3. Was it easy to understand your position and orientation on the mobile map of LandNavin?
4. Did you like the rotated map? If yes, would you use it alone or always in combination with a North-up map?
5. Did you like the reverse overview+detail (dual) map? Was it easy to understand where you were in both views and the relation between them? Did it reduce your need for continuous zooming-in / out?
6. Did you like the idea of multiple-paths? Was it easy to find your way based on that? How about the time availability influence on multi-paths? Do you find it a useful function? Would you change anything in the way the multi-paths appear on the map (colours etc.)?
7. Was the provision of landmark visibility information useful and accurate for you? Would you like to change something in the way this information appears (e.g. change of colour of the circle that surrounds the global landmarks)?
8. Did you find the pop-up information adequate? Would you like to add or change something in the information types available? Did you find the landmark multi-perspective photo idea useful or not and why?
9. Did you like the scaling of landmark icons depending on the zoom level of the map? Were the symbols and icons easy to understand?
10. Was the movement of the scale bar following your position on the map helpful for your tasks? Did you make use of the rotating compass?

11. Was the interface response fast enough for you? Did you easily understand the meaning of the on-screen buttons and their state?
12. Did you find the landmark filtering based on your position and orientation useful? How about the change of the number of the presented landmarks from rotated to North-up map (all visible in the latter)?
13. What were the problems that you experienced during the use of LandNavin which probably reduced your orientation and navigation performance and what are the functions that could be improved in LandNavin so that it meets your needs and expectations better?
14. Would you use LandNavin for you future travels if it was possible to have coverage of the city of interest and why?
15. Any additional comments / suggestions / ideas?

Appendix 7: Example of transcription of research materials for one test person

Test person: TP19

Pre-selection questionnaire file: TP19_pre-selection_questionnaire.docx

Video files: TP19_video_1.avi, TP19_video_2.avi

Interview audio recording: TP19_interview.mp3

Day of test: 29/08/2010

Area: Amsterdam centre

Application sequence: LN, GM

Time availability: Little

1st destination start time: 11:56:35, end time: 12:42:56 (duration: 0:46:21)

2nd destination start time: 12:43:22, end time: 13:11:45 (duration: 0:28:23)

1st destination navigation only duration (LN): (12:14:09 – 12:34:46 and 12:36:56 – 12:42:15 minus 0:06:25 [delays]) = **0:19:31**

2nd destination navigation only duration (GM): (12:52:18 – 13:05:01 and 13:07:06 – 13:10:47) = **0:16:24**

Delays due to rain: none

Delays due to other reasons: 12:14:51 – 12:18:04 (fixing a problem with the map rotation and wrong calibration of the compass); 12:21:06 – 12:22:04 (restarting the application); 12:28:28 – 12:30:42 (fixing a problem with the map rotation and wrong calibration of the compass).

Interruptions by people asking about the research: none

Answers:

1st Task (LN) (11:57:36 – 12:08:17)

a. "Yes".
b. Success.
c. She correctly identified the landmark filtering depending on her orientation.
d. She located Historical "Royal Palace" and Commercial / office building "Rembrandt Tower" and she could also recognize it on the map.
e. She clicked on Commercial / office building "De Bijenkorf Amsterdam" and she says the photo is clearly recognizable and of the same angle as viewed in reality.
f. Found: Metro station "Nieuwmarkt"; distance: about 430m (correct); Time needed: around 4 minutes (correct). Direction: correct.
g. She located: Historical / Church "Westerkerk". Direction: correctly identified and verified after walking for 20m.

2nd Task (LN) (12:09:13 – 12:14:09)

a. Success.

b. She correctly identified the differences between the two multi-paths.
c. Distance to the destination: 700 to 800m (correct); time needed: around 7 minutes of walking (correct).
d. Completed successfully.
e. She correctly walked towards the destination using the “DEST” arrow and correctly verified the destination direction.
f. She identified Museum “Madame Tussauds”, Super Market “Etos” and Café “Club Stereo” (all correct).

g. (12:14:09 – 12:34:46):

At 12:13:56 she does a 1-level zoom-out to observe a more general view of the route.

At 12:14:26 she does a 2-level zoom-in to have more detail of the routes and immediately afterwards 1-level zoom-out.

At 12:18:07 she does a 1-level zoom-in and observes the multi-paths on the map. Then she says she will try to find Supermarket “Etos”.

At 12:18:29 she stops for 11 seconds and says that the compass is not accurate (but it is actually).

At 12:19:56 she says that she thinks she is not on one of the multi-paths but she knows the road so she still can go that way. She is informed that she should try to keep going on the multi-paths.

At 12:22:28 she clicks on Shop “Blokker” to verify her position and right afterwards she says that she thinks she sees it in reality as well.

At 12:22:48 she says she will try to find another shop while she is clicking on its icon (Shop “Original Levi’s store). Afterwards she says that she thinks it is in front of her in reality.

At 12:23:31 she clicks on Shop “Zara” to verify again her position.

At 12:24:09 she stops for 111 seconds while entering a pedestrian crossroads and does 2-level zoom-in and then clicks on Restaurant “Eethuis l’ Mirakel” and then Shop “Fred de la Bretoniere”. Then she does some panning and clicks on Shop “Zara”. Afterwards she does 1-level zoom-out and some panning. Then she does 1-level zoom-out and observes the routes on the map. She says that the position changes all the time and she is informed that this is normal when you are between tall buildings. She insists saying that without an accurate GPS position she cannot understand where she is and she doesn’t have time to try to find other references for estimating her position.

At 12:26:28 she stops again for 10 seconds and says that the compass is wrong again (not true – there is only GPS fluctuation).

At 12:27:31 she stops for 30 seconds and says that the compass is wrong again (not true – it is just more sensitive that time to the movement of the mobile device).

At 12:33:14 she clicks on Office “Huren Amsterdam” which is close to her on the map to verify her position.

3rd Task (LN) (12:35:20 – 12:36:56 / TP stopped at 12:34:46)

a. Completed. She located a local landmark along the route: Bridge (Mixed) and a global landmark towards the destination: n/a.
b. Distance: 30m (around 80m in reality), time needed: several seconds (actually around 1 minute).
c. Direction: Correctly identified and correctly verified.

d. (12:36:56 – 12:42:15):

She continues using the dual map.

At 12:38:25 she stops for 19 seconds (while having already passed the destination addresses and looks for street numbers. She then looks at the map and does 2-level zoom-in. Then she reverses her moving direction (correct) looking at the street numbers, while she is saying that she should have passed the destination already (true).

At 12:38:56 she stops for 71 seconds and looks at the map, then she changes the map to North-up and she does 1-level zoom-in and some panning while inspecting the multi-paths and her destination. The GPS position shown is totally wrong (est. 100m away from the real position) Then she does 1-level zoom-in and some panning and she says that the destination should be somewhere around there.

At 12:40:13 she stops for 91 seconds. She clicks on the destination icon and observes the photo and the address shown. She says that she can recognize all the landmarks she passed by recently, but the destination is wrong (not true – she didn't observe it properly). She then does 1-level zoom-in and she says that she doesn't know where she is. She says that she doesn't have any indication about the destination. Then she says that she has to go to the beginning of the street to find address numbers (not true – most of the buildings in that street have street numbers on).

At 12:42:06 she says that she found the destination (true).

4th Task (LN) (12:42:16 – 12:42:56 / TP stopped at 12:42:15)

e. She says that this is the correct destination and it is recognizable on the map.
f. She says that the photo is recognizable but the angle is not correct, as it is taken from a distance and you have to see it from a distance to recognize it easily.

-- Changing interface and destination -------------------------------------

1st Task (GM) (12:43:22 – 12:48:57)

a. "Yes".
b. Success.
c. N/a
d. She sees the canal in front of her and she says that it is recognizable on the map as well.
e. She clicks Museum "Bijbels Museum" and she says that from her position she cannot recognize the provided photo because it is taken from further distance and it shows only the lower part of the building.
f. Found: Tram stop "Leidsestraat". Distance: about 400m (correct), time needed: about 4 min. (correct). Direction: wrong (around 6 p.m. or 180 degrees out of the correct direction).
g. She located: Huis "Marseille" Direction: wrongly identified (around 6 p.m. or 180 degrees out of the correct direction) and wrongly verified after walking towards that landmark for 20 meters.

2nd Task (GM) (12:49:11 – 12:52:18)

a. Success.
b. N/a
c. Estimated distance: 1km (correct); time needed: 12 minutes of walking (correct).
d. "Yes".

e. She wrongly moved towards the direction of the destination (around 6 p.m. or 180 degrees out of the correct direction) and verified that wrong as well.
f. N/a
g. **(12:52:18 – 13:05:01):**

At 12:52:12 she does 1-level zoom-in observing the route to the destination and then 1-level zoom-out. Then 2-level zoom out. Then she does 1-level zoom-in and some panning observing the route to the destination.

She is keeping the mobile device upside-down during this task and also rotates it around.

At 12:52:58 she does 1-level zoom-out and some panning observing the route.

At 12:53:03 she stops for 37 seconds, rotates the mobile device around and does some panning saying that she is trying to understand where she is and how she should go to the destination. Then she starts moving to the opposite direction of the initially selected (correct) one. She says she hopes that this is the correct directions, but she is not sure about that.

At 13:00:04 she does 1-level zoom-out, observes the route and then she does 2-level zoom-in. Then she does 1-level zoom-out.

At 13:01:57 she does 1-level zoom-out.

At 13:02:06 she stops for 48 seconds, checks the route, does 2-level zoom-in and then 1-level zoom-out. She recalculates the route to the destination ad observes the route again and the destination position.

3rd Task (GM) (13:05:04 – 13:07:06 / TP stopped at 13:05:01)

a. She says she cannot identify any landmarks along the route as there are no existing ones there (not true).
b. Distance: 200m (correct); Time needed: about 2 min. (correct).
c. She wrongly identified and wrongly verified the direction of the destination (9 p.m. or 90 degrees to the left of the correct direction).
d. **(13:07:06 – 13:10:47):**

At 13:07:26 she says that now she can locate a café that is also shown on the map.

At 13:08:12 she does 1-level zoom-in, observes the route and then she does 1-level zoom-out.

At 13:08:19 she does 1-level zoom-in to see more information about the destination and its surroundings. Then she clicks on the destination icon and also does 1-level zoom-in.

At 13:09:29 she stops momentarily and clicks on the destination icon again while she checks the address numbers on the buildings across the street (it is the street of the destination).

At 13:09:44 she says that what she sees here is a street number of 111 while she needs to find 87 , so it is somewhere in the front (correct).

At 13:10:48 she stops in front of the destination and she says that it is there (correct).

4th Task (GM) (13:10:51 – 13:11:45 / TP stopped at 13:10:47)

a. She says that this is the correct destination but it is not so clearly recognizable on the map.
b. She says that she cannot see any photo that is correctly showing the destination building.

Interview answers (18:04 min.)

1. Q: What are your general remarks regarding navigation with the use of LandNavin alone and in comparison to Google Maps?
   A: She says that the map rotation can be really helpful but only when it works correctly, as she faced many problems with that due to sensor inaccuracies.
2. Q: Which of the two routes do you remember better in terms of the surroundings along the route? What do you think is the reason for that?
   A: She says that she remembers the second route (GM) better as she had to pass several canals and that helped her to remember it.
3. Q: Was it easy to understand your position and orientation on the mobile map of LandNavin?
   A: She says no, because she had many problems understanding where she is using LN. She states that this was due to GPS and compass inaccuracy problems.
4. Q: Did you like the rotated map? If yes, would you use it alone or always in combination with a North-up map?
   A: She says that she liked it but personally she is used to personal maps with fixed orientation which she can rotate by her own even if the street names etc. become upside-down. Because of that when she could not get used to the rotated map and sometimes she even became a bit nervous and afraid of those rotating things. She would prefer a stable thing. She would use mostly a North-up map but the rotated one is also very useful many times if it is accurate, as it shows you directly the direction that you are looking at.
5. Q: Did you like the reverse overview+detail (dual) map? Was it easy to understand where you were in both views and the relation between them? Did it reduce your need for continuous zooming-in / out?
   A: She likes it, as she says you don't have it on paper map, and you can get in detail a very small part of the map around you which is really useful. She easily understood her position and orientation in both views as well as the relation between them. She says it reduced her need to do a lot of zoom in and out and as she is an impatient person she gets nervous doing that, which involves waiting for the map to load as it is internet-based. So she likes the dual map that provided her with direct overview and detail information at once without the need for zoom ins and outs.
6. Q: Did you like the idea of multiple-paths? Was it easy to find your way based on that? How about the time availability influence on multi-paths? Do you find it a useful function? Would you change anything in the way the multi-paths appear on the map (colours etc.)?
   A: She says that the multi-paths really help you get ideas about direction to the destination and you can still choose your own route according to the multi-paths or not. She adds that the roads are already on the map so you don't need different multi-paths based on your time availability to be shown on the map. You can select them by yourself. So far she cannot think of a better way that the multi-paths appear on the map than what it is currently.
7. Q: Was the provision of landmark visibility information useful and accurate for you? Would you like to change something in the way this information appears (e.g. change of colour of the circle that surrounds the global landmarks)?
   A: She says that it is nice and showing these global landmarks and their visibility is especially important and interesting for tourists. She adds that the accuracy was not always very good, showing in red actually visible landmarks. But given that it works properly, she finds it a very useful function.

8. Q: Did you find the pop-up information adequate? Would you like to add or change something in the information types available? Did you find the landmark multi-perspective photo idea useful or not and why?

   A: She finds the pop-up information enough. She prefers to have only one photo of the landmarks.

9. Q: Did you like the scaling of landmark icons depending on the zoom level of the map? Were the symbols and icons easy to understand?

   A: She says that the scaling of the icons was just fine. She also easily understood the symbols and she adds that she liked that sometimes you see the shape of the buildings which is nice.

10. Q: Was the movement of the scale bar following your position on the map helpful for your tasks? Did you make use of the rotating compass?

    A: She would prefer a fixed scale bar. She used the rotating compass sometimes and she says that for people who don't have strong preference to the stable (North-up) map it could be really useful as you get the feeling that you are really inside the whole thing. She adds that in that case the users get the feeling that the map is totally the same as where they are, and when they face something in reality they also face it on the map which is nice.

11. Q: Was the interface response fast enough for you? Did you easily understand the meaning of the on-screen buttons and their state?

    A: She finds LN's response much better than GM. She says she is also aware that it is internet-based so some delays are expected when you press a button etc. She easily understood the meaning and the state of on-screen buttons.

12. Q: Did you find the landmark filtering based on your position and orientation useful? How about the change of the number of the presented landmarks from rotated to North-up map (all visible in the latter)?

    A: She prefers to have the landmarks all the time on the screen, even with the rotated map.

13. Q: What were the problems that you experienced during the use of LandNavin which probably reduced your orientation and navigation performance and what are the functions that could be improved in LandNavin so that it meets your needs and expectations better?

    A: She says that the main problem was not the application itself but the problems with the GPS and digital compass accuracy that she faced, and they can reduce the feeling of safety of the user.

14. Q: Would you use LandNavin for you future travels if it was possible to have coverage of the city of interest and why?

    A: She says she would not use LN not because of LN issues in particular, but because she likes paper maps.

15. Q: Any additional comments / suggestions / ideas?

    A: She again mentions about the advantages of paper maps for her and especially the scale-related issues with small screens. She says that the dual map is a good idea towards solving these issues.

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Summary

Using a mobile navigation system or, in other words, a geo-mobile application for orientation and navigation is increasingly becoming popular nowadays as people's mobility increases. These applications, mostly relying on cartographic interfaces, offer a convenient alternative to paper maps with increased interactivity. However, most of them are not very well suited for pedestrians. The special contexts of use and users, the limitations of the mobile devices and the technology-focused solutions provided are some of the main reasons for that. To deal with this problem, the main aim of this research is the design, implementation and testing of a more usable mobile interface for pedestrian navigation. In following a User-Centred Design (UCD) approach, an extensive overview of the current problems of geo-mobile applications was performed first and the available solutions to these problems were evaluated. Landmarks appear to be a very important element that connects reality, mobile maps and the mental maps of people when orientating and navigating. To further understand the role of landmarks but also to gather the information needs of pedestrian users of geo-mobile applications in real contexts of use, a field-based experiment was executed. This experiment belonged to the requirement analysis phase of this research and the participating test persons were representative users of geo-mobile applications travelling to an unfamiliar city. Through task analysis done on the experimental findings, the interactions of the users in four discrete tasks of orientation and navigation were determined. Besides, the corresponding information requirements and sources of disorientation were categorized. Use case modelling was then applied to establish system design requirements for a usable mobile navigation interface and specific, new technical solutions were proposed (such as multi-path routing, landmark visibility information provision and reverse overview+detail maps). Based on these guidelines, a prototype interface, named LandNavin, was implemented in the JAVA Android software environment, directly executable in Android mobile phones. To assess the usability of the completed prototype, a second field-based experiment was executed, again in real contexts of use with representative users. A custom-made field-based observation and recording system was used to successfully carry out the usability testing of LandNavin using very low human resources. As such, video observation (in combination with synchronized screen and action logging and thinking aloud) was the main research method applied. The analysis of the results showed that the efficiency, effectiveness and user satisfaction achieved in orientation and navigation tasks using LandNavin adequately met the predetermined usability

requirements. Moreover, in the given context of use, the prototype exhibited better usability than the Google Maps application which was also tested for comparison purposes. Ultimately, most of the applied technical solutions were very well accepted and valuable feedback was collected from the test persons for improving them further.

Samenvatting

Het verbeteren van de bruikbaarheid van navigatiesystemen voor voetgangers

Nu de mobiliteit van mensen toeneemt, wordt het gebruik van mobiele navigatiesystemen of, met andere woorden, geo-mobiele toepassingen voor oriëntatie en navigatie steeds populairder. Deze toepassingen, die meestal gebaseerd zijn op cartografische interfaces met toenemende interactiviteit, bieden een gemakkelijk alternatief voor papieren kaarten. De meesten zijn echter niet erg geschikt voor voetgangers. Enkele van de belangrijkste oorzaken daarvoor zijn de speciale contexten van gebruik en gebruikers, de beperkingen van mobiele apparaten en op de technologie gerichte oplossingen. Om dit probleem aan te pakken is het belangrijkste doel van dit onderzoek het ontwerp, de implementatie en het testen van een meer bruikbare mobiele interface voor de navigatie door voetgangers. Met toepassing van een benadering van gebruiksgericht ontwerpen werd er eerst een uitgebreid overzicht verkregen van de huidige problemen van geo-mobiele toepassingen en werden de beschikbare oplossingen voor deze problemen geëvalueerd. Oriëntatiepunten ("landmarks") blijken zeer belangrijke elementen te zijn, die werkelijkheid, mobiele en cognitieve kaarten van personen met elkaar verbinden wanneer zij navigeren en zich aan het oriënteren zijn. Om de rol van oriëntatiepunten beter te begrijpen, maar ook om de informatiebehoeften te verzamelen van voetgangers en gebruikers van geo-mobiele toepassingen in werkelijke gebruikscontexten, werd er een veldexperiment uitgevoerd. Dit experiment behoorde tot de behoefteanalyse fase van dit onderzoek en de deelnemende proefpersonen konden worden beschouwd als representatieve gebruikers van geo-mobiele toepassingen die zich in een onbekende stad begaven. Middels een taakanalyse, uitgevoerd op basis van de resultaten van het experiment, werden de interacties van de gebruikers bepaald voor vier specifieke taken op het gebied van oriëntatie en navigatie. Bovendien werden de corresponderende informatiebehoeften en bronnen van gedesoriënteerdheid in categorieën ingedeeld. Vervolgens werden gebruikscasussen gemodelleerd om de systeemontwerpseisen vast te stellen voor een bruikbare mobiele navigatie interface en werden specifieke nieuwe technische oplossingen voorgesteld (zoals multipad routering, het verschaffen van informatie over de zichtbaarheid van oriëntatiepunten en "omgekeerde" overzicht + detail kaarten). Op basis van deze richtlijnen werd een prototype van een interface, LandNavin genaamd, geïmplementeerd in de JAVA Android software omgeving, op zodanige wijze dat het prototype direct uitvoerbaar was op Android mobiele telefoons. Om de bruikbaarheid van het voltooide prototype te beoordelen werd er een tweede veldexperiment uitgevoerd, opnieuw met representatieve gebruikers in realistische gebruikscontexten. Hiervoor werd er een speciaal veldobservatie en-opnamesysteem gemaakt en dit werd met een zeer kleine inzet van menskracht gebruikt om met succes het bruikbaarheidonderzoek van LandNavin uit te voeren. Als zodanig was video observatie (in combinatie met gesynchroniseerde vastlegging van schermactiviteiten en handelingen, alsmede hardop denken) de belangrijkste toegepaste onderzoeksmethode. De analyse van de resultaten liet zien dat de efficiëntie, effectiviteit en gebruikerstevredenheid, die bereikt werden bij de uitvoering van oriëntatie- en navigatietaken met behulp van LandNavin, op adequate wijze overeen kwamen met de vooraf bepaalde bruikbaarheideisen. Bovendien was de bruikbaarheid van het prototype –in de gegeven gebruikscontext- groter dan de Google Maps toepassing die ter vergelijking ook getest werd. Uiteindelijk werden de meeste van de toegepaste technische oplossingen zeer goed ontvangen, maar werd tegelijkertijd van de proefpersonen waardevolle terugkoppeling verkregen ter verdere verbetering van die oplossingen.

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