Exploring the User Interaction Design and Contextual Aspects of an Indoor Navigation System

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Abstract

The research described in this thesis aimed to investigate the design and development of digital indoor navigation systems by focusing on user interaction and contextual aspects. In addition, this thesis explores the potential of using existing technology within building environments in order to use a cost-effective approach and to enrich the visitor navigation experience. The intention was to examine the interplay between components such as personal mobile phones, situated displays and multi-dimensional route presentations. Past literature concerning indoor navigation systems has mainly involved investigating the technical and technological feasibility of novel systems. Therefore, there is limited understanding in terms of user motivations, requirements, preferences, patterns of use, and the impact of the system's context of use on user interaction. Furthermore, there is a lack of research that explores the potential of exploiting non-navigation specific technologies within buildings for supporting navigation.

The objectives described above were carried out by using formative study methods in the Infolab21 building at Lancaster University, and by developing the prototype Hermes2 navigation system. The prototype system underwent several incremental iterations in order to explore user interaction with various functionalities and combinations of components. By using an ecologically valid approach, such that the system was used in its intended environment, and with participants who had no previous exposure to the building's layout, a number of valuable insights were gained from the studies. These insights are presented in the form of design implications, such as the impact of social norms on user interaction, the importance of reassurance, the effects of the cultural characteristics of the system components, and so forth. The experiences with the Hermes2 deployment over a period of

four years have also provided an appreciation of the challenges with the management of ubiquitous display systems. These experiences and findings are intended to assist designers to develop similar interactive indoor navigation systems that match closely to user needs.

Declaration

The material presented in this thesis is the result of my own independent research, under the supervision of Dr. Keith Cheverst, carried out in the School of Computing and Communications at Lancaster University. The text of this thesis is partly based on the following publications:

Taher, F., Cheverst, K., Harding, M., and Fitton, D. (2009). Formative studies for dynamic wayfinding support with in-building situated displays and mobile devices. In *Proceedings of the 8th international Conference on Mobile and Ubiquitous Multimedia*, pp. 5.

Taher, F., Cheverst, K., and Harding, M. (2010). Exploring Personal Mobile Phones and Digital Display Systems to Support Indoor Navigation by Formative Study Methods. *International Journal of Handheld Computing Research (IJHCR)*, *1* (3), pp. 32-50.

Taher, F., and Cheverst, K. (2010). Exploring requirements for tools to support a pervasive in-building navigation application. In *Proceedings of the 12th International Conference on Human-Computer Interaction and Mobile Devices and Services*. *Workshop on Tool-Support for Mobile and Pervasive Application Development.*

Taher, F., and Cheverst, K. (2011). Exploring user preferences for indoor navigation support through a combination of mobile and fixed displays. In *Proceedings of the 13th International Conference on Human Computer Interaction with Mobile Devices and Services*, pp. 201-210.

The research carried out in this thesis was funded by an EPSRC studentship. Part of the work has been previously submitted as a Master's thesis in September 2008. No written material from the Master's thesis has been used. The work has been presented in this thesis due to its relevance and to provide a clearer understanding of the research. Therefore, all aspects with the design and development in relation to the Hermes2 navigation system were my own independent work.

The work carried out with the Hermes2 deployment is a continuation of the previous CASIDE[1] project, which involved Dr. Keith Cheverst, Dr. Dan Fitton, and Mike Harding. However, the insights developed in this thesis of the Hermes2 system are entirely my own work.

[1] http://www.caside.lancs.ac.uk/ (last accessed 21st March, 2013).

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Chapter 1

Introduction

Ongoing technological advances have enabled researchers to investigate novel ways of supporting visitors in complex building environments through personalized, continuous, and context/location-aware digital navigation applications. A typical scenario in complex multi-level buildings (e.g. hospitals, institution buildings, shopping centres, etc.) involves arriving late (for an important appointment perhaps), getting lost, experiencing frustration and eventually arriving at the destination location feeling agitated. These issues can be caused by situational factors where visitors might forget directions, overlook signage, become distracted by time pressure, and/or limitations in the design of signage and architecture (Arthur and Passini, 1992).

Past research into indoor navigation systems has mainly focused on the technological aspects and demonstrating the functional feasibility of these systems through measuring user performance, system performance, and positioning accuracy. Thus, more qualitative insights into whether these systems closely match user interaction requirements, and understanding the systems' context of use, are limited. Furthermore, the potential of utilizing existing and non-navigation specific digital resources (e.g. digital displays) within modern buildings is under-explored. A survey of mobile indoor navigation systems by Huang and Gartner (2010), for instance, exposes the lack of research into ways in which instrumented indoor environments can optimize visitor navigation.

The first objective of this thesis is to investigate user interaction with indoor navigation systems. More specifically, we are interested in user preferences, motivations, requirements, and patterns of use with combinations of technologies and devices for indoor navigation support. These include personal mobile phones, situated displays, and multi-dimensional route presentations. The intention is to form a rich understanding of users, as well as the suitability and usefulness of the above components, in order to inform the design of indoor navigation systems that match closely to user needs.

In addition, it is important to consider the social and environmental aspects which can affect the ways that users interact with navigation systems. Therefore, the second objective is to investigate the contextual factors that influence and shape user interaction with the navigation system components described above. The aim is to explore the issues and considerations that emerge from device ownership, privacy of navigation tasks, and the effects of social conventions.

The third, and final, objective of this thesis involves exploring the extent to which an existing ubiquitous display deployment in the Infolab21 building at Lancaster University, known as Hermes2, can be adapted for the purposes of supporting visitor navigation. The Hermes2 system was initially designed to support a shared messaging application that promotes awareness in the workplace by, for instance, allowing their respective owners to set messages for, and receive messages from visitors. We believe that the structural aspects of this deployment and the functionality of the messaging application can benefit visitor navigation, as well as reduce the cost and complexities of implementing new and separate infrastructures.

To address the objectives described above, the prototype Hermes2 navigation system was developed and evaluated by conducting formative user studies in the Infolab21 building. The system comprises of the following components.

- The Hermes2 display deployment, a kiosk-style touch-screen display, and personal mobile phones.
- Route presentations such as digital 2D maps, first-person 3D route visualizations, and graphical signage.
- A navigation application that enables users to receive directions to their destination, as well as assistance whilst they are en-route, through a Graphical User Interface.

The Hermes2 navigation system was not designed to be a polished end-product, but to facilitate research into the areas of indoor navigation system design, through formative study methods, which has limited understandings of user interaction and context. In addition, the user studies with the prototype navigation system enabled us to form an understanding of the extent to which existing technologies, such as the Hermes2 display deployment, can be usefully adapted for supporting visitor navigation.

1.1 Definition of Terms

This section clarifies the intended definitions of key terms used throughout this thesis.

Wayfinding

The term wayfinding was first used by Kevin Lynch (1960) and it is defined as "consistent use and organization of definite sensory cues from the external environment". Wayfinding involves the perceptual, cognitive and decision-making processes that are necessary to find one's way in a space (Arthur and Passini, 1992). In this thesis, the term wayfinding is utilized during discussions involving spatial cognition (see chapter two).

Wayfinding Performance

Wayfinding performance refers to the user's ability to successfully reach their destination given the constraints imposed by the environment, time and cognition. Golledge

(1999) discusses that no two wayfinding attempts are alike due to factors such as short-term variations (e.g. alertness, detours in the environment), long-term changes (e.g. slower response times due to aging) and of course, uncertainty.

Navigation

The formal definition of navigation concerns the notion of “steering” or “directing” (e.g.an aircraft or ship) (Golledge 1999) and it is colloquially defined as *“to deliberately walk or make one’s way through some space”*. This thesis adopts this definition such that navigation represents the action of being directed between two locations in a space. Therefore, unlike wayfinding, navigation is generally associated with a simpler process which does not involve aspects such as orientation, strategies, and so forth.

Navigation System

In this thesis, a navigation system is represented as a digital system. Therefore, a navigation system refers to a set of interdependent digital components designed to aid users to find their way between locations. The system can involve route presentations, client devices, positioning technologies and context-aware services.

Route Presentation

A route presentation refers to information or the representation of space that is designed to assist and direct users between locations (i.e. help users navigate). A common form of route presentation is a floor plan, which is typically found within building environments such as shopping centres.

Location-awareness

Location-awareness refers to the ability to geographically locate a mobile or situated device. In the context of navigation, location-awareness enables users to determine their position in the environment. A typical example involves in-car navigation systems which continuously show the driver's current location (and orientation) through, for instance, an arrow graphic on a map-based presentation.

Positioning

Positioning refers to the technologies and techniques used to determine the user's geographical location on, for instance, a mobile device. An early example of a positioning system is the Active Badge system (Want et al, 1992), which is based on infrared technology. It uses an infrared-based sensor network placed along the ceiling, which relays data to a master server. User location is determined by requiring them to wear a badge that emits a unique ID every few seconds, which are then picked up by the sensor network.

Context-awareness

Context-awareness combines location-awareness with the ability to recognize and adapt to the changes in the surrounding environment (Schilit et al 1994). Context-awareness is related to aspects such as: where you are, who you are with, and what resources are nearby. The use of context-awareness can be characterized by a system's (e.g. a tourist guide application on a mobile device) ability to react to nearby locations of interest and display relevant and useful information (e.g. Cheverst et al, 2000).

Location Model

A location model is a digitally stored representation of the environment (e.g. of a specific building) which enables location and/or context-aware systems to acquire information about distances between objects, objects contained in specific areas (e.g. rooms, digital appliances), and orientation (Becker and Durr, 2004).

Situated

In this thesis the term situated is used in the context of public displays. Situatedness involves the physical location in space, as well as the social behaviors and conventions that are associated around it (Harrison and Dourish, 1996; O'Hara et al, 2003). For instance, the displays integrated in the Hermes2 system are described as situated displays.

1.2 Research Questions

The research questions detailed below investigate the use of the prototype Hermes2 navigation system in order to gain insights into user interactional aspects, context of use, and the feasibility of the Hermes2 deployment for supporting navigation. These investigations are carried out using formative study methods, as well as through experience-related insights gained from the management of the Hermes2 deployment over a period of four years.

1) **In what ways do users prefer to interact with an indoor navigation system that comprises of personal mobile phones, an existing situated display deployment (i.e. Hermes2) and a set of 2D and 3D route presentations in an unfamiliar building environment? What interaction and contextual design implications can be extrapolated from the user preferences?**

Although past research has demonstrated the functional feasibility of a number of novel indoor navigation systems, there is limited qualitative insight towards the ways in which these systems support user interaction, and how they factor in the influences of their context. A review of indoor navigation systems in published literature carried out by Huang and Gartner (2010) indicates that there is little work focusing on evaluating the suitability and efficiency of route presentations such as digital 2D maps, 3D representations, graphical signage, and so forth. For instance, navigation systems such as the Rotating Compass (Rukzio et al, 2009) reveal qualitative insights and observations towards the interplay between mobile phones and situated displays, but these insights are limited to observations in an outdoor context. There is limited understanding of aspects such as user requirements and preferences. The Smart Signs system (Lijding et al, 2006), which was designed to provide personalized navigation support in building environments, was mainly evaluated in terms of the system's performance and only reveals general user attitudes towards the overall use of the system. A more qualitative approach is effectively required in order to investigate the ways in which the various components of indoor navigation systems can be tailored towards the needs of users. It is important to note that a functional navigation system that successfully and accurately directs users between locations does not necessarily constitute that the system is user-friendly, customizable and easy to use.

The research described in this thesis aims to expand on the understandings of indoor navigation system design by utilizing a user-centered approach to uncover key interactional and contextual insights. This aim was carried out by conducting a series of six separate formative user evaluations where participants were exposed to the prototype navigation system, and were involved in detailed discussions about their experiences. The evaluations were designed to enable participants to interact with various combinations of displays (e.g. mobile phones and situated displays), route instructions (e.g. 3D route visualizations, maps, and graphical signage), and functionality (e.g. downloading route visualizations and receiving location-aware support). The approach for each of these evaluations is discussed in more detail in chapter three. Another key objective is to explore the ways in which the environment (or contextual factors) affects user interaction with the navigation system. We investigated aspects such as ownership, privacy and social norms in relation to personal mobile phones and public situated displays for indoor navigation support. For example, we explored the effects of the structure and functionality of the Hermes2 deployment, which is originally tailored towards a messaging application (e.g. the placement of the displays enables visitors to identify which display belongs to an office occupant).

2) To what extent can the physical and software components of the Hermes2 display deployment be adapted to assist visitor navigation and mitigate the requirement for a new digital infrastructure?

One of the key challenges of developing and deploying indoor navigation systems involves the need for additional hardware infrastructures to provide location-aware support. For instance, infrared, ultrasound, or radio frequency (e.g. Bluetooth, RFID, Wi-Fi) based systems require the installation of additional sensor networks (Liu and Darabi, 2007). Fortunately, technological advances are enabling radio frequency based sensors to become less costly, as well as integrated into every-day mobile devices (e.g. Smartphones with Bluetooth capability). Furthermore, the pervasiveness of modern Wi-Fi hotspots in urban locations is removing the need for installing additional hardware to achieve positioning, thus enabling developers to focus more on software development. However, another key and persistent challenge involves achieving accurate positioning through the use of algorithms to address multipath and signal strength issues (Liu and Darabi, 2007).

This thesis explores the use of the Hermes2 display deployment in a multi-faceted context. We investigated the potential of providing navigation support by showing content on the displays. This was motivated by the structure of the deployment, which is designed such that on turning a corner, a user would “expect” to see more displays, rather than be surprised to see them. In addition, the deployment consists of a network of situated displays supported by a central server. Given the existing infrastructure, and the ubiquity of display placement, we explored the potential of configuring the display content to serve as positioning and orientation tools (i.e. users would be able to receive location-aware support by using an application running on the displays). Furthermore, we investigated the suitability of the messaging application software, which is supported by the displays, as a means of assisting visitor navigation. As the messaging application enables the respective owners of the displays to set publicly viewable messages, as well as receive messages from visitors, we believe that its functionality is very relevant for supporting navigation.

There is little work investigating how existing, and non-navigation specific, technology in modern buildings can be adapted and we believe that the Hermes2 display provides an opportunity to investigate the ways in which these displays can reduce the complexities of developing indoor navigation systems, as well as enrich the navigation experience by means of its messaging application. For instance, the relevance of the situated displays for supporting visitor navigation has already drawn interest and collaboration from the managing director of a commercial signage company.

3) What can be learnt about the technical, as well as administrative, responsibilities and challenges of managing an existing ubiquitous display deployment that is adapted for supporting visitor navigation?

This thesis also describes the challenges that are associated with managing and adapting the functionality of a shared display system for the purposes of navigation over a four-year period. The Hermes2 system was originally designed to be a test-bed for various research projects, thus allowing flexibility for researchers to adopt the role of an administrator. Observations and experiences over a four year period helped develop an appreciation of the day-to-day activities and responsibilities associated with managing the Hermes2 system. Such activities involved attending to the needs of its users and addressing technical challenges that emerged over time. The insights gained from longitudinal experiences are intended to inform designers of indoor navigation systems who might choose to utilize similar ubiquitous display systems.

1.3 Research Approach

The research questions described in the previous section were addressed by carrying out six formative user studies involving the prototype Hermes2 navigation system and through longitudinal experiences with managing the Hermes2 deployment. Rather than using a purely lab-based approach, we were interested in observing the use of the navigation system in a more "natural" setting. Therefore, the user studies were designed to be ecologically valid with varying levels of control. The levels of control across the user studies were determined by anticipating the way in participants used the features of the prototype navigation system (e.g. if a feature was not used in a particular study, participants were encouraged to do so in the next study). Infolab21 was an ideal environment for the studies as it already supported the Hermes2 deployment, and furthermore, it provided the opportunity to investigate the use of the prototype system in its intended environment. We also recruited participants who were unfamiliar with the layout of the building. The findings from the studies were then analyzed by using methods inspired by grounded theory, and also discussed by using ideas from activity theory. Descriptions of grounded theory and activity theory are provided in chapter three.

In addition to the user studies, we also report on the challenges of managing a ubiquitous display deployment (i.e. the Hermes2 deployment). Activities such as resolving technical issues, addressing requests and queries of display owners, and general system monitoring activities were logged using an online blog over a four-year period.

This thesis also builds on preliminary research which has provided a foundation for our work. A short investigation into display sharing and ownership issues was carried out by Kray et al (2006). This study examined the potential of sharing the functionality of Hermes2 displays in terms of both its original messaging application and a navigation application known as GAUDI. Although the GAUDI navigation system is not explored in this thesis, the findings relating to display control are relevant and further explored in this thesis and in the context of the Hermes2 navigation system. Furthermore, a preliminary formative user study was carried out in August 2008 with an initial prototype of the Hermes2 navigation system (Taher, 2008). The data gathered from this study is utilized in this thesis, and are described in more detail in chapter five.

1.4 Thesis Structure

This thesis is structured as follows. The next chapter, Background, provides a comprehensive literature review of the relevant research concerned with Indoor navigation and exposes the gaps which are addressed by the research described in this thesis. This chapter firstly begins with examining the fundamental challenges with indoor navigation, including spatio-cognitive challenges, architecture and the challenges of adapting existing commercial systems. Secondly, this chapter reviews the relevant components of indoor navigation systems such as route presentations, client devices, positioning techniques, context-awareness and location modelling. A review of indoor navigation systems in published literature and the ways in which they have utilized and tested the above components is also provided.

Chapter three provides a background towards the methodology used in the research described in this thesis, including user-centered design, prototyping, grounded theory, and activity theory. This is followed by a description of the ways in which these methods have been adapted in our research, and also reflections on the choice of these methods.

Chapter four describes the Infolab21 environment in which we carried out the research, and the configuration of the Hermes2 navigation system. The functionality and infrastructure of the Hermes2 system and messaging application is described, as well as the responsibilities and issues associated with managing the deployment. Furthermore, the components and design choices of the prototype Hermes2 navigation system are described, which includes personal mobile phones, route presentations (i.e. three-dimensional route visualizations, digital maps, graphical signage) and the adaptation of the situated displays.

Chapters five, six and seven describe the approach, evaluation process, analysis of findings, and the limitations of each set of user studies which address our objectives of exploring interactional and contextual aspects of the various components of the Hermes2 navigation system. Furthermore, these chapters explore the feasibility of adapting the situated display deployment for the purposes of supporting visitor navigation. In more detail, chapter five focuses on the user motivations and interaction preferences with personal mobile phones and various route presentations, chapter six investigates the feasibility of using the situated display deployment for supporting navigation, as well as contextual factors that influence display interaction, and chapter seven explores interactional and contextual factors of the combined use of components that are integrated in the navigation system.

In chapter eight, a discussion of the user studies is provided and a framework for indoor navigation system design and development is proposed (consisting of key categories and interaction design guidelines). We also describe the limitations and the generalizations of the research described in this thesis. Finally, in chapter nine, we conclude by re-examining the research questions, describing the contributions into the domain of indoor navigation and suggesting potential areas of exploration as part of further work.

Chapter 2

Background

Indoor navigation research encompasses a large and diverse body of work that has sought to develop novel systems driven by technological innovations. Furthermore, the design of these systems has utilized existing knowledge from cognitive psychology in order to aid the development of route presentations. This chapter firstly examines the fundamental challenges of indoor navigation that has motivated the research in this thesis. More specifically, this involves bringing in knowledge from architectural and cognitive psychology, as well as investigating the difficulties associated with adapting commercial solutions. We refer to the term wayfinding rather than navigation whilst discussing cognitive and architectural aspects. Wayfinding encompasses a broader meaning as it involves the perceptual, cognitive and decision-making processes that are necessary to find one's way in a space (Arthur and Passini, 1992). Secondly, this chapter surveys relevant literature involving the variety of digital components that are required for the development of indoor navigation systems, including route presentations, client devices, positioning technologies, context-aware services and location models. This is followed by reviewing existing indoor navigation systems in published literature and the ways in which these systems have utilized the various components.

2.1 Fundamental Indoor Navigation Challenges

Wayfinding difficulties within complex multi-level building environments such as (but not limited to) hospitals, shopping centres, airports and office buildings are caused by a combination of factors. These include architectural configuration, the calibre of signage, a person's spatial ability, familiarity, and situational aspects such as anxiety, frustration and time-constraints. Regardless of one's spatial ability or situational constraints, it can generally be asserted that it is easier to navigate within a well-designed building with coherent and consistent signage compared to, for instance, a building which has a confusing layout and illegible signage. Wayfinding has attracted attention from psychologists, geographers and urban planners in exploring the ways in which people process and use spatial information (Golledge, 1999) in order to understand the reasons behind wayfinding issues and what makes one person "better" than another at successfully finding their way. It is unfortunate that when buildings are constructed, wayfinding can end up at the bottom of the list (Arthur and Passini 1992) with focus on factors such as function, aesthetics and cost-effectiveness. The following subsections examine the underlying issues of wayfinding that derive from the cognitive factors and the environment, as well as the challenges of adapting well-established commercial solutions.

2.1.1 Spatio-Cognitive Challenges

Newcomers to an unfamiliar building generally face orientation related challenges, such as "where am I?" and "how do I get to a specific location?" To solve this problem a number of steps must be considered, including previous experiences of similar environments, reading and evaluating the environmental context, assessing the spatial characteristics of the environment, and gathering information from signs, maps and other indicators (Arthur and Passini, 1991). In addition, situation-dependent factors such as time, interest, and security must also be considered. Golledge (1999) provides a detailed analysis of the ways one can learn a new environment, including: (1) active search and exploration, (2) familiarization with secondary information such as maps, sketches, verbal descriptions, photographs, and so forth, prior to arrival, (3) use of navigation practices such as exploration using path integration (e.g. to keep knowledge of where "home base" is located), exploration and retrace methods, exploration by boundary following, and so forth. Thus, learning an environment can be generalized into (1) learning by directly experiencing it through travel and (2) learning by using symbolic, analog or iconic modelling.

2.1.1.1 Spatial Knowledge and Cognitive Maps

The three most commonly known forms of spatial knowledge that can be learnt from the environment are introduced by Siegel and White (1975), and these involve landmark, route and survey knowledge. Landmark knowledge aids in identifying one's position in a specific location and the available decision points from that location. Newcomers exploring a location might, for instance, rely on landmarks as reference points. Route knowledge comes with further experience of the environment and enables the sequential connection of these landmarks to form routes. Finally, survey knowledge incorporates landmark and route knowledge to develop an overall configuration of the environment. Survey knowledge can be gained in two different ways. In the first scenario, a person might observe a map of the location, thus viewing the location from an allocentric perspective, and is able to understand the various configurational relationships from a bird's eye view. Secondly, a person is exposed to an environment over a long period of time and therefore, by experiencing various routes from an egocentric perspective, is able to build a similar configurational relationship to that of a map learner (Ruddle et al, 1997). Such a person who has developed survey knowledge of a location, for instance, can identify various routes and choose the most convenient path to a destination location The acquisition of the three forms of spatial knowledge contributes to the development of the cognitive map (Tolman, 1948), which aids people in carrying out wayfinding tasks (e.g. selecting optimal paths to destinations or knowing when one is lost). The term cognitive map was coined by Edward Tolman (1948) and it is used to describe the internal representation of spatial information that can aid people in tasks such as finding their way home.

The ease of organizing information about the environment in a coherent pattern is determined by the legibility (or clarity) of the environment (Lynch 1960). Although Lynch's research is focused on outdoor environments such as cities, the principles discussed can also be adapted for building environments. Lynch (1960) provides a classification of five interrelated elements which build the "image" of an environment, including (1) paths, which are channels in which a person moves through (e.g. walkways), (2) edges, as organizing features that provide boundaries between regions, (3) districts, which encompass medium to large sections of an environment, (4) nodes, which are strategic areas such as junctions or decision points, and (5) landmarks, which are external points of reference.

2.1.1.2 Spatial Processing

The utility of the cognitive map comes into effect when users process the spatial information and are able to successfully traverse routes on subsequent occasions. This processing of information is described by Golledge (1999) as involving two distinct levels: actions within the physical environment (i.e. observable behaviours such as exploration) and spatial mental representation (i.e. provided by the sensory environment). The behavioural aspect is sequential in that it is organized into actions such as "go ahead" and "turn left". Golledge (1999) suggests that the mental representation is part of a more complex system where, for example, if there is a change in the environment (e.g. a new route or landmarks) then the exploratory behaviour will be reactivated in order to update the mental representation.

While long-term exposure to an environment can help develop an accurate cognitive map (Ruddle et al, 1997), Taylor et al (2008) suggests that this process can be sped up by strategically presenting wayfinding information to users. For example, in the context of navigation systems, spatial information should be presented visually whilst action and descriptive information should be presented verbally. In addition, wayfinding information should be tailored to meet spatial information preferences and effectively communicate navigational goals (Taylor et al, 2008). An interesting question here is whether wayfinding information presented to users should encourage spatial learning or simply aim to direct the users to their destination as quickly as possible. Hölscher et al (2007) suggests that reduced spatial learning can be an unanticipated side-effect of, for instance, omnipresent directions provided to users.

2.1.1.3 Spatial Ability

There is no simple answer to why some people are better than others at wayfinding performance. A variety of factors can contribute to the level of an individual's spatial ability (Allen, 1999). Spatial ability has been studied in a number of different domains using various methods. For instance, spatial ability has been measured through psychometric testing (typically in a lab setting), which are designed to test participants in terms of their visualization, rotation and spatial orientation abilities. In more detail, visualization concerns the ability to imagine or anticipate the appearance of complex figures; rotation (or spatial relation) concerns the ability to determine whether one stimulus is a rotated version of another; and spatial orientation relates to the ability of an observer to anticipate the appearance of objects from a specific perspective. Domains such as information-processing and developmental psychology address spatial phenomena including the differences in the way that individuals understand information from various systems, their ability to store information in memory obtained from these systems, and the ways in which individuals perform tasks such as computing distance and estimating directions to target locations. The information-processing domain suggests that individuals typically differ in the way that they process tasks and utilize their working memory. Developmental psychology complements this domain by observing age related effects on the improvement of these tasks. Sas and Noor (2009) provide a meta-analysis of the relationship between testing procedures and users' environmental spatial abilities. It was found that a self-reported questionnaire was an effective tool in determining levels of spatial abilities (e.g. sense of direction). What can be understood from these domains is that, for instance, if a cognitive map means memory of a spatial layout, it is reasonable to suggest that individuals who are able to form more accurate cognitive maps are better at finding their way (Allen, 1999).

2.1.1.4 Gender

A number of studies have measured and discussed the effect of gender differences in spatial processing whilst carrying out wayfinding tasks (e.g. Kruger et al, 2004; Saucier et al, 2002; Galea and Kimura, 1993; Linn and Petersen, 1985). Kruger et al (2004) carried out a user study with 32 participants in an unfamiliar location with two conditions: audio-based instructions and visual instructions. Kruger et al (2004) found that female participants performed better with the visual condition than the audio condition, whilst male participants performed equally with both conditions. Galea and Kimura (1993) carried out a user study with 97 participants involving map-learning and testing (e.g. cognitive testing, Euclidean knowledge) and found that female participants performed better with recalling landmark knowledge. However, no significant differences were visible in terms of route learning strategies and Euclidean distance estimations. Saucier et al (2002) carried out a user study with 42 participants, who were required to complete navigation tasks in unfamiliar locations using Euclidean-type instructions and landmark-type instructions. The study showed that male participants generally performed better with Euclidean-type directions, whilst female participants performed better in the landmark-type instructions condition.

It is evident that the differences in spatial ability (as introduced in section 2.1.1.2) between men and women are debatable, however there are clear differences in terms of the effectiveness of the strategies used to learn environments. Devlin and Bernstein (1995) analyse a number of past studies on this topic and indicate several examples where males used cardinal directions more frequently than females, females demonstrated a more accurate sense of distance than males, and studies which revealed no differences at all. The studies show that there is a tendency for males to perform better with planning efficient routes and using Euclidean coordinates, whereas female tend to perform better with visual and more meaningful representations. Galea and Kimura (1993) utilized an evolutionary framework and speculated that in a hunter-gatherer society, Euclidean cues may have supported males for hunting food, whereas females found landmarks more useful at near distances. Voyer et al (1995) analyze various studies on gender differences and spatial ability, as well as the methods used to test them, and suggest that certain tests are more likely to demonstrate differences than others (e.g. during tests where participants are required to carry out mental rotation tasks).

2.1.2 Architecture and Signage

In addition to cognitive factors, the legibility of a building environment has significant impact on wayfinding performance (O'Neill, 1991; Werner and Schindler, 2004). Whilst it can be difficult to find one's way through a complex building environment, signage can generally compensate (O'Neill, 1991a) for wayfinding issues. However, Arthur and Passini (1992) provide an example of a building in Montreal which, despite investment into signage to improve wayfinding, architectural issues such as split levels, confusing spatial organization and repetitive features was still far too problematic. Weisman (1981) identifies four separate environmental variables that affect wayfinding performance, including visual access to settings, architectural differentiation, the overall layout of a setting and the quality of signage provided.

2.1.2.1 Visual Accessibility

The visual accessibility of a building relates to the visibility of parts of a building (for instance, through windows) from every other part (Gärling et al 1983). One can imagine that it is easier to find one's way with good visual access to different parts of the environment, for instance, by noticing through the window that the building has three levels. An early study carried out by Gärling et al (1983) in a two-storey university building indicated that, after having artificially reduced participants' visual access to a few meters using specially devised goggles, even those who were familiar with the building had issues finding their way. Hölscher et al (2006) provide an example of a poorly situated entrance hall in a conference facility (which is typically regarded as a "hotspot" area) with a substantial lack of visual access to other areas within the building. The authors found that the lack of visual access left users inside the entrance hall unable to view available navigation choices, such as the route to the exit. Passini (1996) argues that features such as entrances, exits, landmarks and staircases are features which must be communicated by architecture alone and, for instance, should not rely on support from signage.

2.1.2.2 Architectural Differentiation

The extent to which one location looks "different" to another gives that location its identity (Arthur and Passini, 1992) and allows the location to be easier to recognize, thus affording better wayfinding performance (Weisman, 1981). It would indeed be very difficult to navigate in a building where all the rooms and corridors looked similar (Fewings, 2001). Carlson et al (2010), for instance, describe a rather problematic set of four floors organized in a spiral structure in the Seattle Central Library where all corners on every level appear to be identical. The authors found that the lack of differentiation caused users to repeatedly reorient themselves whilst they were walking up or down the spiral. Passini (1992) suggests that distinctiveness can be straightforwardly achieved through the use of finishes, textures, lights, colours and graphics, all of which are resources that designers typically have at their disposal. Arthur and Passini (1992) describe the notions of identity and equivalence which refer to two categories of architectural differentiation that designers must consider. While it is important to be able to differentiate between spaces (through their identities), the notion of equivalence states that users must also be able to group such distinctive spaces into zones using common characteristics. For instance, various reception areas in buildings can appear distinctive and have their own identity but at the same time, reception areas tend to have similar characteristics such as seating facilities, a receptionist with a prominent desk, information leaflets, and so forth.

2.1.2.3 Layout

It is necessary for the design of the building architecture to also facilitate the learning process of a building's overall layout, as opposed to relying solely on resources such as signage. Passini (1992) encourages the use of geometrical forms and laws, such as Gestalt, in order to organize the layout of a building. Simple geometric forms (such as an 'L' or 'T' shape) are more effective for wayfinding (Arthur and Passini, 1992; O'Neill, 1991a) in comparison to, for instance, typical large hospital environments that consist of several interconnected buildings. Of course, it is also possible to understand the organization of an arbitrary path (Passini, 1992) given that there are prominent landmarks in place which can help serve as mental reference points that enable users to easily remember specific spaces. A clear and well-expressed organization of building layout is especially necessary for large complex building environments.

In addition to simple form, buildings must also have a comprehensible circulation system (Passini, 1996; Raubal and Egenhofer, 1998; Holscher et al, 2006; Werner and Schindler, 2004) which defines the main pattern of building use. Passini (1984) found that, in a study involving more than 100 participants, nearly half of the participants had a tendency to include an organizational structure whilst drawing (through recall) a mental map of a commercial shopping centre. The organizational structure involved a large central square around which shopping areas were set-up. O'Neill (1991b) found that an incremental increase in the complexity of a building's layout significantly reduces wayfinding performance. Similarly, an early study carried out by Best (1970) with 135 participants in two large buildings found a correlation between the number of decision points within a building and wayfinding difficulties. Therefore, there is a clear relationship between the complexity of a building's layout and wayfinding difficulty. Taylor, Brunyé and Taylor (2008) describe the ways in which our environment can vary, such as the size, shape and density of landmarks, path network structure, topography and stability. Taylor, Brunyé and Taylor (2008) argue that the more complex the environment is on the aforementioned dimensions, the more likely a user will require wayfinding assistance.

Multi-level buildings pose further challenges for user orientation as climbing a staircase or an elevator can impair a person's heading due to rapid changes in direction (Holscher et al, 2006). Montello and Pick (1993), by carrying out a user study, demonstrate that participants had difficulties aligning vertical spaces (e.g. in pointing tasks). Holscher et al (2006) argue that vertical circulation is an essential component of good building design and that one of the key elements involves positioning the stairways such that they are optimized in relation to the user's activity in the layout.

2.1.2.4 Graphic Communication

Graphic communication (such as maps and signage) goes hand-in-hand with architectural communication in determining wayfinding performance. Whilst architecture can facilitate wayfinding, signage is essential in providing information regarding *where* a destination is located and *how* to reach it. This is necessary especially in complex building layouts. The London Underground and Paris Metro, for instance, are examples of environments that rely on the design of maps, signage and architecture in order to enable travellers to successfully reach their destination areas and platforms. Signage can be categorized as textual (e.g. digits, words or phrases) and graphical (maps, symbols or icons). In addition, designers can use other means for developing visual signs, such as using colour or markings on the walls to represent a unique location within a building. A study carried out by O'Neill (1991a) explored three conditions of signage (no signage, textual signage, and graphic signage) and found that graphic signage enabled the highest rate of travel for participants, whilst textual signage was more effective in reducing errors.

Signage in the form of graphical arrows and text is typically associated with less cognitive costs in comparison to maps, as following signs does not require actions such as strategic planning, self-localization and translating the abstractions presented on a map into the physical environment (Shelton and McNamara, 2004; Holscher et al, 2007). Maps, however, are able to provide more information than a single sign-post. Like architecture though, the design of signage must address issues such as ambiguity, conflicting information between old and new signage, incomplete or excess information, illegibility, obstructions and unreliability (Arthur and Passini, 1992).

2.1.3 Situational Constraints

As common sense suggests, familiarity with a building or a setting certainly enables better wayfinding performance. Garling et al (1983) for instance, found that familiarity significantly facilitated orientation with a building. In contrast, Best (1970) discusses that it is likely that a person in a strange environment for the first time will be careful to get accurate directions whereas a person who has been there before will think he "remembers" where to go. It can nevertheless be argued that even though the overconfidence of a familiar user can cause problems due to paying less attention to the environment, the properties of the environment (e.g. architectural design, landmarks, colour coding) should enable recognition rather than recall (Arthur and Passini, 1992; Dogu and Erkip, 2000).

Emotional factors such as fatigue, anxiety and discomfort can definitely contribute to wayfinding difficulties. Passini (1996) discusses the notion of situational impairments such as emotional upheaval, anger, joy, stress and fatigue, which can affect our cognitive abilities and how effectively we can find our way. Being late for an appointment and finding one's way through an overly crowded location can certainly induce such negative emotions. Even forgetting to wear glasses or carrying heavy loads that restrict mobility can contribute to wayfinding difficulties. Hund and Minarik (2006) investigated the relationship of spatial anxiety, wayfinding strategies and navigation efficiency. The authors found that as spatial anxiety increased, the amount of errors increased, as well as the time needed to complete navigation tasks.

There are of course, various reasons for the ways in which we locate our destination. Fewings (2001) discusses three different techniques, including recreational, resolute and emergency wayfinding. Here we focus on recreational and resolute, as the domain of wayfinding in emergency conditions is not within the scope of the research described in this thesis. Recreational wayfinding offers more flexibility in terms of problem-solving and finding out where to go next can itself be a goal and provide satisfaction. In this case, the user is not in a hurry and is thus, more likely to avoid negative emotions. In resolute wayfinding, the user seeks the most efficient way to their destination location. Here the complexity of the environment and the way that architecture and signage are designed can have a significant impact on the user. A tourist with plenty of time in a complex environment may have a pleasant experience exploring the area. However, a delivery man trying to deliver a parcel in a complex and confusing environment under time constraints might find the experience frustrating.

2.1.4 Adapting Existing Commercial Solutions

The most successful commercial digital navigation systems, which are designed to supplement traditional forms of signage such as printed maps, are used within outdoor environments. Global positioning satellite technology (GPS), which was initially developed in the early 1960s for military purposes (Getting, 1993) in the USA, became fully operational for the public to use in 1994 and have since enabled users to track their location whilst navigating by using mobile devices. With the aid of 24 orbiting satellites, devices with GPS receivers are typically used within ground, air and sea vehicles (e.g. a Tom-Tom in a car) and, more recently, by pedestrians (e.g. Google maps on a mobile phone). The ability of GPS to determine a user's location with an accuracy of just a few meters, as well as its wide coverage across the globe, are significant contributors to its popularity. The signal strength from the satellites can, however, be subject to limitations. These include signal interference by weather conditions and urban canyon environments (Cui and Sam-Ge, 2003) that contain high rise buildings, and other large obstructions (e.g. bridges). It is nearly impossible for the satellite signals to penetrate built environments, making it challenging to easily adapt existing navigation systems that rely on GPS signals for indoor use. Furthermore, the nature of multi-level and therefore, vertical navigation styles within building environments (Kargl et al, 2007) can cause further issues as GPS signal is much less accurate in terms of detecting altitude.

Indoor spaces can certainly be challenging and harsh environments (Mautz, 2009) as typical buildings contain various walls and obstacles with various materials. These characteristics can cause difficulties in achieving accurate and precise positioning. The limitations with adapting existing GPS-based navigation systems for built environments has encouraged research into alternative methods of achieving indoor positioning, including using technologies such as radio signals, infrared, ultrasound, vision systems, dead reckoning and other experimental approaches (Mautz, 2009; Liu and Darabi, 2007; Huang and Gartner, 2010). Additional infrastructure can be installed within buildings such as GPS repeaters, which are able to amplify GPS signal using a rooftop antennae. Repeaters can then be placed in various indoor locations to amplify the signal (Mathis et al, 2005). However, like approaches with infrared and ultrasound, the limitation of this approach is that a building must install additional equipment, which can be costly in terms of time and effort. Another key issue for the lack of commercial and standardized indoor navigation systems concerns the availability (or lack of) of mapped indoor spaces, in comparison to outdoor environments. While most of the outdoor world has been thoroughly mapped, digital maps of buildings are less common. The issues arise from the building owners who may or may not be willing to enable the digitization of their floor plan.

In recent years, commercial incentives (e.g. Meridian[2], Google Maps indoors[3]) are attempting to enable the widespread use and digitization of indoor maps. The integration of

[2] http://www.meridianapps.com/ (last accessed 10th January 2013).

various motion technologies such as accelerometers and gyroscopes in modern Smartphones are also encouraging this process. These technologies can aid the optimization of positioning that might already be achieved using GPS, or WiFi signals. Positioning techniques are discussed in more detail in section 2.2.3. Meridian, for instance, offers a Software Development Kit (SDK) for Android and iOS platforms, as well as a content management system for building owners which can be utilized to manipulate location content. Meridian uses Wi-Fi connectivity to achieve positioning. Similarly Google has launched a campaign for building owners to upload their floor plans in order increase availability of mapped indoor spaces. Google's My Location technology utilizes cell tower identification to provide users with location information. The ubiquity of mobile and Wi-Fi hotspots facilitates this process and removes the requirement of installing additional infrastructure within buildings. Another commercial example is the IndoorAltas[4] system developed in Finland. This system uses a different approach by exploiting built-in Smartphone magnetometer sensors to detect magnetic fields in order to achieve positioning (IndoorAtlas Ltd., 2012).

2.1.5 Summary

Wayfinding is affected by cognitive as well as environmental (e.g. building architecture, signs) factors. It is essential to understand the way in which we acquire knowledge of our environment in order to adequately design architecture and signage systems that enables us to, for instance, develop an accurate cognitive map. It is also clear that the challenges of indoor spaces have caused difficulties in adapting digital and commercial solutions which, for instance, are already utilized in outdoor locations. However, advances in technology and incentives towards digitizing indoor spaces have lead to the inception of widespread digital solutions that can aid visitors in complex environments

[3] http://maps.google.com/help/maps/indoormaps/ (last accessed 4th February 2013).
[4] http://www.indooratlas.com/Technology (last accessed 14th January 2013).

and supplement existing (and more traditional) methods of navigation support (e.g. printed signs).

2.2 Digital Indoor Navigation Systems

Digital technology can enrich the wayfinding experience for users in complex building environments by offering personalized, multi-modal, and location-aware assistance. It must be noted that the intent of such navigation systems is not to replace traditional forms of support (e.g. printed signs and maps), but to supplement it. This section firstly describes the components that are necessary for the development of indoor navigation systems, including route presentations, types of client devices, positioning techniques, context-awareness and location modelling. Following this, a review of indoor navigation systems is provided to examine the ways in which the approaches towards integrating the various components have been utilized and tested.

2.2.1 Route Presentations

One of the key requirements of indoor navigation systems involves the ways in which route information is presented and communicated to the user. The efficiency and usefulness of route information is generally determined by how easily users are able to successfully find a location with minimal cognitive load (Huang and Gartner, 2010). Huang and Gartner (2010) list the forms of route presentations which have been utilized by various digital navigation systems, such as maps, text-based or audio instructions, directional signs, images, videos, 3D presentation, augmented reality and vibrations.

2.2.1.1 Signage

Visual graphical signage (as introduced in section 2.1.2.4) such as graphical arrows, are typically self-explanatory and navigating from sign to sign requires low cognitive load

(Holscher et al, 2007; Huang and Gartner, 2010). For instance, following a sign at a decision point or being instructed to carry on down a hallway does not require users to self-localize or interpret abstract environmental representations. In digital navigation systems, signage can be coupled with other types of route presentations, such as maps or 3D representations of the environment. For instance, turn-by-turn applications (Hermann et al, 2003) such as those used in GPS systems within vehicles to show direction and turn-based information. The advantage of digital signage is that the signs can be tailored to a particular user as well as enabling them to naturally use navigation cues located in the environment (Kray and Kortuem, 2005). The Smart Signs system (Lijding et al, 2006), for instance, enables users to view personalized graphical arrows (combined with textual instructions) on situated public displays. A user evaluation comparing the use of printed signage and Smart Signs signage in a university building revealed fewer navigation errors and fewer cases of users being lost whilst using the Smart Signs system. Digital signage can also adapt to the context, for instance, if a particular route becomes unusable (Lijding et al, 2006) or if a public display is re-positioned (Kray and Kortuem, 2005).

2.2.1.2 Audio, Textual and Haptic Instructions

Text and audio-based navigation instructions can be classed as similar to each other, albeit presented through different modalities. Text-based instructions demand visual attention, whereas audio instructions enable users to focus on the environment. In-car GPS systems normally use audio instructions so that the driver can focus on important factors such as traffic, driving in the correct lane, and so forth. Another way to enable users to focus more on the environment is to use vibration-based navigation instructions. The GentleGuide navigation system (Bosman et al, 2003), for instance, experimented with using wearable wrist devices, which vibrated in order to provide indoor navigation assistance to users. The devices were designed to be worn on each wrist and instructions for turning left, right, wrong turn and arrival were mediated through vibrations on specific sides and with specified durations. However, to support users in more complex environments, the wrist devices need to be supplemented by other types of presentations such as maps. Similarly, text and audio instructions on their own are inadequate for portraying complex spatial relationships (Towns et al, 1998). The Rotating Compass system (Rukzio et al, 2005), for instance, utilizes vibration on a mobile phone as a means of alerting the user when the relevant graphical arrow is shown on a public display.

2.2.1.3 Maps

Maps are generally regarded as the most commonly used resource (Kray et al, 2003) for enabling user orientation and providing route directions (e.g. road maps, You-Are-Here maps, etc.). One significant advantage of maps is that the bird's eye perspective enables users to learn configurational relationships between the properties of an environment (Thorndyke and Hayes-Roth, 1982). These include the location of objects in the environment relative to a fixed coordinate system (i.e. compass bearings), shapes of land features (e.g. rooms, hallways) and distances between locations. The presentation of maps must take into account several factors including: alignment with the environment, scale, level of abstraction, level of detail, degree of schematization, and level of precision (Montello and Freundschuh, 1995). One of the most important elements of successful maps is their ability to communicate to users (Dent, 1972) in terms of the symbols, shapes and other markers that are represented. For instance, the symbols need to be familiar and their visual impact must be closely associated with intellectual meaning. Devlin and Berstein (1997) suggest that some of these guidelines reflect Gestalt principles (Koffka, 1935), which is unsurprising as the elements of a map must be integrated into a visual whole that can be easily understood by the reader. A badly designed map leaves the user visually and intellectually confused, thus taking the user an unnecessary length of time to decipher various components of the map (Dent, 1972). With regards to map alignment, a number of studies have revealed that maps are easier to use for navigation when they are "up" or aligned with the user's forward direction (Rossano and Warren, 1989; Aretz and Wickens, 1992; Shepard and Hurwitz, 1984) as objects are then in congruence to the user's egocentric perspective.

Devlin and Bernstein (1997) evaluate the effectiveness of three map variables on wayfinding performance, including colour, level of detail and the location of map information (e.g. placement of labels). It was found that landmarks on a map that required additional steps for identification (i.e. using a number key on a label), caused participants to be less efficient in locating the goal site and reduced wayfinding efficiency. The authors also failed to find any significant effects pertaining to the level of colour and detail towards wayfinding performance. In other words, users found it neither unfavourable nor beneficial for wayfinding. Factors such as scale must also be taken into account, that is, whether the scale of the representation's space matches that of the user (Montello and Freundschuh, 1995). If it does not match then the user will be required to carry out a scale translation to gain an understanding of the space.

Visualizing maps on digital display devices (e.g. mobile phones and fixed displays) can provide a number of benefits for users, but at the same time create a number of challenges. These challenges include determining the level of fidelity and scope of map information to be shown to users, as well as determining the level of interactivity to include. It can be asserted that a map shown on a situated digital display is somewhat similar to a printed static map, albeit with the potential to integrate dynamic and interactive features such as information that is tailored to individual users. For example, a number of digital kiosk displays in the Arndale shopping centre in Manchester, United Kingdom allows users to select a destination location (e.g. a shop or facility) using a graphical user interface, and view the route from their current location to their destination (using animations) on a map. This particular navigation system only displays the relevant floors centred on the user's current and destination location and the detail is kept minimal, that is, it only shows the annotated route, labelled intersection points, icons representing the lift or staircase (if they are required to be used in the route) and the name of the destination location.

Displaying maps on mobile devices (e.g. on a mobile phone or tablet computer) introduces a variety of complexities pertaining to scale, ease of reference, and detail levels (Willis et al, 2009). These complexities derive from a combination of zoomable graphical user interfaces, the ability to provide dynamic visualization (e.g. based on GPS positioning), and the generally smaller viewing area of a mobile device. In particular, the ability to zoom in and out of a map raises the question of how much environmental detail and information is needed to be visualized at different zoom levels. Google Maps, for example, allows users to view more detail of the environment the more they zoom in (e.g. from the names of streets to roads and landmarks). The benefit of dynamic visualization enables users to track their location and orientation with, for instance, a moving You-Are-Here (YAH) marker in the form of a directional graphical arrow. In other words, the user's motion is traced in real time over a graphical representation of the environment (Willis, 2005). Seager and Fraser (2007) discuss that these types of map presentations (or turn-by-turn presentations) require mobile devices to rely heavily on accurate and reliable positioning (e.g. from GPS signals) which can be problematic if there is signal interference. The Cyberguide system (Abowd et al, 1997) is an early example which explored context-aware indoor navigation support for tourists by providing map-based route presentations on a Personal Digital Assistant (PDA). The approach was based on showing a limited view of the environment (through the map on the PDA) at any given time. However, it was also important to show the user's position in the limited view. Hermann et al (2003) investigate the effects of similar, and more "egocentric", views of a map on mobile devices for navigation. Here the maps are dynamically adapted around the user's current position (e.g. similar to Cyberguide). The authors found in their user study that participants made absolutely no navigation errors.

The notion of map alignment must also be addressed as mobile users could be constantly changing orientation. Seager and Fraser (2007) address the alignment issue by examining whether users prefer physical, manual or automatic map rotation by carrying out a user study with 16 participants. The physical rotation proved to be the least cognitively demanding and most useful for participants as they simply needed to rotate the mobile phone. Methods of rotation such as manual (through the press of a button) required a higher mental workload, the automatic condition rotated the map without the user knowing, and north-up simply required strategies such as mental rotation.

In addition, users on the move typically need to attend to various tasks such as the people around them, what their plans are later, whether they're in the correct location, and so forth. Thus, due to the divided nature of attention, one of the limitations of maps presented on mobile devices is the constant requirement for attention, which could potentially cause wayfinding errors (Willis et al, 2009). The fragmented nature of attention whilst using mobile phones is further discussed in section 2.2.2.1.

2.2.1.4 Three-Dimensional Presentations

Three-dimensional representations of the environment (often referred to as 3D maps or virtual environments) are able to provide users with a digital simulation of the physical environment. Witmer et al (1996) describe a virtual environment (VE) as a computer-generated simulated space with which an individual interacts. In contrast to learning the environment from a bird's eye perspective (e.g. from a map), in a 3D representation, users are able to directly experience the environment (much like in real life) with the added benefit of various perspectives (Satalich, 1995) including egocentric, exocentric (through flying above the environment), a combination of both, or from an elevated perspective (Froelich et al, 2008). Stahl and Haupert (2006) argue that sophisticated architectural designs such as the Guggenheim museum in New York would benefit from 3D modelling for supporting visitor navigation. One drawback of 3D representations is that configurational understanding of the environment is not immediately gained, and similar to first-hand experience, it would require repeated exposure to the environment over a prolonged period of time. Numerous studies have investigated whether the knowledge gained from virtual environments are transferrable to the physical world (Waller et al, 1999; Satalich, 1995; Richardson et al, 1999; Ruddle et al, 1997). Witmer (1996) demonstrated in a user study that participants who experienced a virtual building (which was still in its infancy in terms of sophistication) were able to successfully transfer route learning skills in the real world. Similarly, Ruddle et al's (1997) user study showed that extended experience to a virtual building environment enabled participants to develop abilities such as near-perfect route finding, accurate estimations of distances and direction. These findings matched the results of Thorndyke and Hayes-Roth's (1982) study where participants physically experienced the equivalent building in real life.

A variety of issues must be considered to determine the effectiveness of learning from a 3D presentation and the ability to, for instance, apply this knowledge in the real world. Waller et al (1999) discuss the notion of fidelity, which is regarded as the extent to which the VE and its interactions are indistinguishable from the user's experience of the real world (in other words, the level of realism and immersion). It is safe to say that real world information would never be preserved perfectly in the virtual environment. Ruddle et al

(1997) argues that a considerable amount of time and effort must be spent in order to achieve higher levels of fidelity. Waller et al (1999) proceed to describe the two levels of fidelity, which are environmental (the degree to which variables in the training environment resemble the real world) and interface (the mapping of the variables from the virtual environment to the user's mental representation) fidelity. It is, for instance, questionable as to whether movement represented through a mouse sufficiently represents interaction with real world navigation. Satalich (1995) describes a number of factors that must be addressed in order to caution enthusiasts, including time of exposure in the virtual environment, the unfamiliarity of medium, behavioural constraints (i.e. participants cannot move naturally and are constrained by digital devices) and the types of cues and tools available whilst learning the environment in the 3D presentation.

There are several ways of improving the learning process of the environment from 3D representations. Ruddle et al (1997) found that participants in the virtual environment used memorable landmarks (e.g. 3D models of everyday objects) to form associations between routes and to trigger direction changes. Vinson (1999) further emphasizes the importance of landmarks in virtual environments and proposes a set of guidelines that focus on the design and placement of landmarks, including number of landmarks presented, distinctiveness, use of concrete objects rather that abstract ones, visibility and the placement of landmarks on major paths and junctions. Ruddle et al (1997) propose that virtual environments could be provided with You-are-here maps, for instance, on a small window that shows the overall layout of the environment. Alternatively, users could be provided with digital maps which could be referred to at any time whilst experiencing the virtual environment. Froelich et al (2008) suggest that an elevated perspective of the surroundings in a virtual environment, as opposed to an egocentric first-person view, would provide a better overview and understanding of the environment for users.

2.2.1.5 Augmented Reality

Azuma (1999) describes augmented reality (hereafter referred to as "AR") as the ability to view the real world through a digital device with virtual objects that are superimposed upon or composited with the real world. AR technology essentially supplements the real world rather than replacing it through the development of a 3D representation. The technology is designed to enhance a user's perception and interaction with the real world (Azuma, 1999). One advantage is that the interaction is more familiar and natural (Narzt et al, 2005) as the user does not have to learn a new external representation (such as a map) and the user can use natural interactions such as hand gestures. Milgram et al (1994) discusses the implications of the term 'augmented reality' due to the gray area between virtual reality (or virtual environments where the user is immersed in a computer-generated environment) and true AR where natural interactions (e.g. gesture-based, eye-movement) are possible through devices such as transparent head-mounted displays. Thus, the term "mixed reality" is proposed as a more suitable description to represent the combination of AR and computer-generated synthetic components.

Two types of digital displays are used for AR-based systems, which include see-through displays and monitor-based displays (Milgram et al, 1994). The former involves being able to see through the display medium using, for instance, head-mounted displays (Feiner et al, 1997; Hollerer et al, 1999; Hollerer et al, 2001; Behringer et al, 2000; Liarokapis et al, 2006). The latter, monitor-based displays, involves overlaying computer generated information onto live or stored video images, such as a live video-feed from a mobile phone camera (Wagner and Schmalsteig, 2003; Pasman and Woodward, 2006; Takacs et al, 2008).

Some limitations regarding these technologies include user comfort and movement restrictions, especially with wearing a head-mounted display and portable PC in a backpack (Narzt et al, 2005). The need to use additional equipment, even if size and weight becomes reduced with technological advances, is a significant factor for the user's motivation to use the system as it may not agree with the user's sense of fashion. The use of mobile devices can be an alternative, however, the interaction style is less naturalistic compared to the wearable computer approach and it is further constrained by factors such as display size.

Another form of mixed-reality systems involves mediated reality, which is defined as the modification of the real world by adding computer-generated virtual components (e.g. arrows) or occluding parts of the environment that might be particularly confusing or unnecessary (Torres-Solis et al, 2009). A sophisticated experimental mediated reality system (MERLA) is presented by Torres-Solis et al (2009), which integrated components such as a web cam, Wi-Fi dongle, a gyro mouse, Wii controller, a wearable computer such as a small laptop and semi-transparent head mounted display. This particular set up enables users to achieve orientation and view route directions by viewing superimposed navigation aids on the head mounted display, including a compass, a map of the environment, and so forth.

A key application of AR, or mixed-reality, involves providing wayfinding assistance as the technology enables users in an unfamiliar environment to view external or obscured information to reach their destination. There is however, limited understanding into whether AR in fact improves wayfinding performance in terms of orientation and cognitive mapping, although various systems have demonstrated functional feasibility. Goldiez et al (2007), for instance, carried out a study in a search and rescue scenario and found that AR map display produced better wayfinding performance in comparison to two control conditions involving map users, and compass users. It must be considered that whilst AR could enable users to find their way to a destination location quicker, it appears that the technology does not necessarily aid in the development of a cognitive map unless the exposure to the environment is prolonged. Maps and virtual environments, for instance, can be generated and viewed a priori, whereas AR technology can be regarded as a means of facilitating decision making during the navigation process. If the task is to successfully find a location as quickly as possible, or if the user has arrived unprepared in an unfamiliar environment, then AR is indeed beneficial.

2.2.1.6 Tools for Developing Route Presentations

Digital representations of maps can be developed by using Computer Aided Design (CAD) tools, for example, AutoCAD[5] or Inkscape[6] which is open-source. This enables the environment to be represented using geometric shapes, which allows designers to factor in distances and angles (see section 2.2.5 on Location Modelling). For instance, architectural floor plans of a building can be converted into CAD format, although these plans must be modified as they contain additional details which may not be relevant for assisting navigation. Furthermore, presentations such as graphical arrows, text and audio instructions do not require sophisticated applications and can be developed by using off-the-shelf image editors and media applications.

Three-Dimensional Model Development

The general architecture surrounding the development of 3D graphics involves an application layer, a rendering framework and the graphics hardware. On the application layer, model data (i.e. geometric shapes), which defines the necessary geometrical and behavioural descriptions of the generated space, can be developed and stored in standardized formats such as BSP, VRML and X3D (Web 3D Consortium, 1999). This data

[5] http://www.autodesk.co.uk/ (last accessed 24th February 2013).
[6] http://inkscape.org/ (last accessed 24th February 2013).

must then be processed by frameworks such as the OpenGL (Khronos, 2003) or Direct3D (Microsoft, 2013) API in order to transform it into a format that the graphics hardware can understand. The graphical processing unit (or GPU) is then able to process this data. An example of this process involves creating a 3D model of an environment using a graphical modelling toolkit, exporting the design as a BSP file and then using a game engine to render the model. Another example involves writing an X3D file (manually or using a development tool) and using a web browser to render the file. In this case the rendering can occur over the network or on the local machine. VRML (and its successor, X3D), along with OpenGL ES, Direct3D Mobile, Mobile 3D Graphics (or JSR-184) APIs are also available for use on embedded devices such as mobile phones, PDAs and games consoles. This creates a significant advantage as one of the essential requirements of navigation is the ability to receive directions en-route.

Several experimental systems have explored the use of model data formats such as VRML and X3D and frameworks such as OpenGL in order to investigate their suitability for supporting navigation tasks. Yamamoto (Stahl and Haupert, 2006; Munzer and Stahl, 2007) is particularly interesting as it was developed as a completely separate map modelling toolkit to support pedestrian navigation (e.g. in indoor environments). The toolkit utilizes the OpenGL API to produce 3D schematic models of building environments and it is able to represent a number of structural elements such as walls, doors, stairs, galleries, and so forth. The MobiX3D system (Nadalutti and Chittaro, 2006) experiments with rendering X3D content using the OpenGL ES API on a PocketPC, thus eliminating the need for a wireless connection for remote rendering. The client device is able to parse and render X3D models as well as manage animation events and user input. The m-LOMA system (Nurminen, 2006) uses a client-server approach where VRML models are processed on a server and model-data, along with location-data, are provided to client devices. Data caching is used to avoid network congestion, which allows least-used data to be released when more memory is required. The LAMP3D system (Burigat, 2005) uses a VRML-based approach on a Compaq iPaq device and enables users to receive information by selecting objects of interest (e.g. by using touch) in the 3D representation. The system also utilizes a flexible approach by offering three modes of interactivity, including GPS-based continuous support, manual navigation support, and previously recorded animated virtual tours.

Game engines provide another means for developing 3D models. Engines such as Quake 3 (Torres-Solis et al, 2009) provide the benefit of being open-source. Customized environments can be modelled using visual map editing toolkits (e.g. GtkRadiant) and then run as a customized level. Another advantage of game engines is that the environment has the potential to achieve a high level of realism (Bylund and Espinoza, 2002) through the use of photographic textures compared to VRML environments. Richardson et al (1999), for example, developed a virtual environment using the Doom 2 game engine in order to carry out a study that measured how well users were able to learn from the VE and navigate in the real environment. The authors found the users were able to learn similarly to real environments.

2.2.2 Client Devices

Client devices fall into two separate categories, mobile and situated devices. Mobile devices have been subject to a broad range of navigation research, due to the mobile nature of navigation. Situated devices, such as public displays, are constrained to specific locations. However, situated displays provide certain advantages, such as a larger display size, which is particularly useful for receiving directions or information about the user’s navigation task.

2.2.2.1 Mobile Devices

One particular challenge that mobile devices have faced in the domain of navigation support is the ability to provide adequate visualization (e.g. as discussed by Chittaro, 2006) due to hardware-limitations. However, recent developments in mobile technology have tackled this issue and devices such as Smartphones are able to, for instance, support high quality 3D graphics. Furthermore, devices such as tablet PCs have also addressed display size limitations. Thus, the key challenges of mobile devices in navigation are more related to their ability to provide adequate spatial knowledge to pedestrians. Vehicle-based mobile navigation devices such as Tom-Toms are already widely utilized and are able to direct users on a global scale to anywhere that has been mapped. However, pedestrian navigation differs in terms of the ability to traverse more complex spaces and at a much slower pace. The question is then raised as to whether it is necessary for users to acquire spatial knowledge of the environment rather than simply being directed between locations. For instance, what happens if the mobile device fails and the user is lost? Will they be able to remember which way they came from?

Mobile Devices for Navigation

Several studies have been carried out in order to measure the level of spatial knowledge acquired by users whilst using mobile devices (e.g. Kruger et al, 2004; Aslan et al, 2006; Ishikawa et al, 2008; Willis et al, 2009). Ishikawa et al's (2008) study compared the level of spatial knowledge acquired between users who used paper maps, had direct experience, and used a GPS-based map navigation device. Results demonstrated that GPS users travelled slower, were less accurate in drawing sketch maps, and found navigation tasks more difficult. Similar findings are reported by Kruger et al (2004) and Aslan et al (2006) found that users who utilized mobile devices for navigation failed to convey survey knowledge and were only able to learn route and landmark knowledge. Willis et al (2009) carried out a user study to compare mobile map use versus a paper map. Their paper provides an in-depth understanding into the causes of poor survey-based knowledge acquisition of mobile map users. Willis et al (2009) discuss the notion that users following mobile phone instructions typically "switch off" and become passive. In contrast, users who used a paper map are able to reflect on the overall configuration and come up with strategies rather than following instructions.

Attention Distribution Challenges

Another key challenge of mobile phones is the relationship between the user's cognitive processes and the interaction requirements of the mobile device. Willis et al's (2009) study, for instance, revealed that users following a mobile map experienced constant attention distribution between the mobile device and the environment. This impacted on their ability to gain adequate spatial knowledge of the environment due to being constantly engaged in resolving map information and information from the physical environment. It is certainly a cognitively demanding task, for example, to pay attention to a mobile phone and, at the same time, to walk through a crowded location. Kristoffersen and Ljundberg (1999), for instance, carried out a user study involving engineers and found that mobile devices posed unsuitable requirements for the users, who had to "make place" for the device. Perry et al (2001) argue that users of mobile devices face a range of contexts (e.g. offices, hotels, rooms, airports, and vehicles), thus being exposed to plethora of unpredictability and uncertainty. Brewster and Lumsden (2003) state that user interaction needs for mobile devices will differ greatly depending on the user's context. Oulasvirta et al (2005) carried out a user study where participants were exposed to a number of different contexts (e.g. laboratory, busy street, quiet street, etc) in order to investigate the distribution of attention between the mobile phone and environment. Results indicated that attention switching was highest in the busy street, where the most amount of attention dwelled on the environment.

Thus, the fragmented nature of mobile phone interaction certainly provides challenges for mobile application designers.

2.2.2.2 Situated Displays

Situated public displays, such as timetable displays in public transport stations, adopt a complex and important role within society and provide a broad range of functionality, such as offering methods of communication, collaboration and coordination (O'Hara et al, 2003). In public spaces displays in the form of kiosks can offer information and services (Maguire, 1999) at the point of need (e.g. ATMs, ticket machine for transport). Another significant aspect of public displays, which is more relevant to our investigations in this thesis, is the politics surrounding display ownership, access and control (O'Hara et al, 2003). These notions are certainly multi-layered as displays provide different functionality to different user groups. O'Hara et al (2003) suggests that public displays are "subject to ongoing processes of negotiation". Digital roadside signage, for instance, does not allow the public to control or manipulate its content and they are only able to take away information. In this case a greater degree of ownership, access and control is given to the content makers. A collaborative digital whiteboard is another interesting example, which provides access to multiple users at once albeit different granularities of ownership. Specific members of a group (e.g. users who are interacting with the board) have a higher degree of ownership than passive audience members.

Situatedness

The situatedness of displays involves the physical location in space and also the social behaviors and conventions that are associated around it (Harrison and Dourish, 1996; O'Hara et al, 2003), for example, the portrayal of ownership and access. O'Hara et al (2003) suggest that the "behavioral characteristics that are associated with places will affect how displays are perceived and used". Muller et al (2009), for instance, found that user expectations of display content and whether they are likely to pay attention to it depend on the perceived context, who they believe the display owner is (including other factors such as visibility, attractiveness, etc). Churchill et al (2003) observed differences in usage levels between three plasma poster displays, which were aimed towards local community members in a software research lab. The displays were placed in a corridor, kitchen and foyer. The kitchen display experienced the most activity due to the nature of the location where users are typically idler compared to corridors and foyers. Furthermore, a survey of public displays was carried out by Huang et al (2008) across three cities in Europe, and revealed the importance of display location towards their success. For instance, Huang et al (2008) observed that people were more likely to look at public displays if other objects nearby caught their attention first. Displays placed at eye-level height also proved to be more effective in attracting user attention.

Proxemic Display Interaction

An important aspect of user interaction with displays is the relationship between the space surrounding situated digital displays and users, which is also known as proxemics (Ballendat et al, 2010). The term proxemics was introduced by Hall (1966) as a theory to describe spatial relationships and the role that they play in dictating how people interact and engage with others and physical objects in the environment. Designers of situated displays can adopt the understandings from Hall's theory of proxemics and develop displays that are able to exploit the proximity of users and, for instance, implicitly react to them. Greenberg et al (2011) describe four key zones that depict interpersonal distance: intimate (less than 1.5 feet), personal (1.5 to 4 feet), social (4 to 12 feet), and public (12 to 25 feet). The importance of proxemic interaction with digital display technologies is apparent when we compare displays that show fixed content in a loop (e.g. advertisements) to those that are able to tune their content to passers-by and their proximity (Wang et al, 2012). Displays such as the Proxemic Peddler (Wang et al, 2012), which was designed as a prototype advertising display, aimed to encourage users to move close to the display (e.g. in order to view and purchase products) as well as attempt to regain their attention. The Hello.Wall display (Streitz et al, 2003) is an early example of an interactive ambient display which reacts to the user's proximity. In this case, users are required to be equipped with a mobile device in order to be uniquely identified by a public display, which aims to ameliorate the workplace atmosphere (e.g. collaboration, monitoring deadlines, to-do lists, etc.).

Social Embarrassment

Social embarrassment is another key factor which can affect interaction with public displays. Brignull et al (2002) draw an interesting analogy where a street performer asks a member of the public to help out. The person might be wary not knowing what is expected of them and whether they would appear foolish in front of others. The authors observed the social dynamics around their Opinionizer public display and found that social embarrassment was one of the key barriers for interaction. Brignull et al (2002), however, observed a "honey pot" effect where users who were in the immediate vicinity of the displays exuded social interest, thus attracting others to cross the "participation threshold" and become involved with display interaction. Muller et al (2010) build on this notion of the participant threshold and describe the "audience funnel" model, which defines various interaction phases (e.g. ranging from looking at the display to directly interacting with the display) that users of situated displays might experience. This model provides implications for the design of public displays. Similarly, Izadi et al (2005) found that users faced social embarrassment whilst participating in a collaborative task if they were positioned in front of a display, with reports of users feeling as if they were "under the spotlight". This notion of social embarrassment reflects the earlier works of Erving Goffman (1959) who suggests that when an individual appears in front of others, she is likely to present herself in a light that is favorable to her. Muller et al (2010) states that “a public display may well be perceived as a stage, and how people interact with it may depend on their personality traits”.

Privacy

Privacy is another important consideration which must be accounted for during the design of situated displays. In public locations, while it is necessary to communicate its purpose, users typically favor privacy depending on the type of information they are seeking from, for instance, a kiosk display (Maguire, 1999). Maguire (1999) suggests that the kiosk must be designed so that the user’s body will conceal the interactions and the information shown on the display from others. Sharp et al (2006) describe the notion of “shoulder-surfing” where “attackers” (i.e. users interested in gaining personal information for malicious activity) stand behind the display user and watch them, for instance, type confidential information on the keyboard. Tan et al (2003), for instance, describe this type of activity as information voyeurism. Huang et al (2008) found in their observations that smaller displays invited prolonged viewing in public spaces in comparison to larger displays. It is suggested that smaller displays may create a private or “intimate” setting where the viewer feels less exposed. Greenberg et al (1999) investigates the nature of public and private artefacts (things created, manipulated and owned by a person or group) involving mobile devices (e.g. PDAs) and single display groupware (SDG). It was suggested that the distinctions between private and public artefacts rely on criteria such as the artefact’s user, its proximity and visibility to others and social conventions surrounding the artefact. These criteria support the claim that smaller displays may create a more private setting, such that interactions are not as readily visible to others in comparison to a large public display.

2.2.2.3 Mobile and Situated Display Interaction

The interaction between mobile devices and situated displays fits in with Weiser's (1991) vision of ubiquitous computing where devices in the environment are able to interact amongst each other. In particular, recent developments into Smartphones are enabling them to become an input device for situated displays (Ballagas and Borchers, 2006). This encourages the foundation for new interaction paradigms, similar to how the mouse and keyboard on desktop systems led to the WIMP paradigm. Ballagas and Borchers (2006) explore the design space for mobile and situated display interactions by reviewing various interaction techniques utilized in research projects and providing a framework that encompasses techniques including positioning, orienting and selecting. A typical example of positioning is being able to control the position of a cursor on a remote display by using the mobile screen as a trackpad (e.g. Remote Commander – Myers et al, 1998). Orientation tasks can involve the physical space as well, for instance, being able to orient a security camera or a steerable projector (Ballagas and Borchers, 2006). Selection tasks encompasses the ability to select tagged objects (e.g. RFID tags explored by Want et al, 1999), use the mobile phone camera (e.g. reading barcodes explored by Rohs et al, 2005), voice recognition and gesture recognition. Patel et al (2004) present a handheld device which is able to authenticate users wanting to access information on their mobile phone through a public terminal by using gesture recognition through the device's accelerometer.

For the purposes of navigation, the interaction between mobile and situated displays can offer benefits such as an alternative screen which addresses the limited screen size of mobile phones (Want et al, 2002). For instance, an early hybrid indoor/outdoor navigation system known as REAL (Baus et al, 2002) exploits the use of larger displays to complement route presentations shown on a mobile phone. The Rotating Compass (Rukzio et al, 2009), involved an interaction technique such that users could receive a vibration prompt on their mobile phone when a situated display showing directional information (e.g. arrows) is nearby. A user study revealed positive feedback towards the synchronized use of the situated displays and mobile phones. Furthermore Muller et al's (2008) user study in an outdoor context provided some interesting insight into user behaviour towards mobile phone and display interaction. Muller et al (2008) found that participants preferred using the mobile phone for navigation support whilst walking, but they used the displays as a means of reassurance or to get an overview of their route.

2.2.3 Positioning

Positioning involves determining the user's current location within the surrounding environment by typically using a digital fixed or mobile device. It helps answers questions such as "where am I?" or "how do I get there?" which are significant for navigation. Outdoors, positioning is mainly achieved through GPS satellite signals and mobile devices equipped with GPS receivers. Indoor spaces require different approaches to either amplify GPS signal using repeaters or utilize different sensors. Furthermore, the dense composition of objects and walls within indoor environments and the multi-storey style of navigation are key factors to take into account towards the design of indoor positioning systems. The components of positioning systems can be categorized into positioning information, technology, and type of infrastructure set-up (or topology) (Liu and Darabi, 2007).

2.2.3.1 Positioning Information

Positioning information types include physical (e.g. coordinates), symbolic (e.g. location expressed in natural language), absolute (fixed point in a shared grid) and relative (position based on proximity to another reference frame). To deliver these forms of positioning information, physical sensors are required to wirelessly communicate information. Furthermore, various location positioning algorithms (e.g. based on triangulation, scene-analysis and proximity) can be utilized in order to determine location by using signal measurements.

2.2.3.2 Positioning Techniques

Triangulation is divided into two methods, lateration and angulation (Liu and Darabi, 2007; Hightower and Boriello, 2001). The former involves signal measurements such as time of arrival (i.e. from the transmitter to the measuring device), time difference of arrival (i.e. difference of transmissions arriving at measuring units from the transmitter), and return time-of-fight (i.e. like TOA but with a return transmission). A limitation of these methods is that they are prone to line of sight issues in indoor environments; however, this can be solved by using signal strength measurements (i.e. RSS). Angulation techniques involve measuring the angle in which a signal arrives to the measuring unit and require at least two reference points (for 2D positioning) or three points (for 3D positioning). Algorithms that use scene-analysis initially survey a location for signals and their unique properties. Location fingerprinting is a commonly used technique with scene analysis, which firstly involves collecting signal data in an offline phase. Following this, during the online stage, signal data is then compared and the location is estimated. Proximity algorithms are simpler and rely on a grid of measuring units, which detect the mobile transmitter signal and location is determined by the unit which detects the strongest signal.

2.2.3.3 Topology

The topology determines the ways in which, for instance, the sensors are structured and whether a client-server model is utilized (Liu and Darabi, 2007). A remote positioning system, for instance, involves a mobile transmitter signalling to various fixed measuring units. The measurements are then computed by a master station. A self-positioning system involves several fixed transmitters in the environment and a mobile unit is able to pick up the signals, measure them and compute its location. This could also be done indirectly through a Wi-Fi connection by sending the measurements to a server to compute the device's location. Another variation of this is indirect self-positioning where the server sends back the measurement results to the mobile device.

2.2.3.4 Deployment Techniques

Indoor positioning system can be deployed using two different techniques. The first technique involves developing a wireless network infrastructure specifically designed for positioning. Although this enables more control for the designers, it can be time-consuming and costly. A pioneering example of a positioning system is Active Badge (Want et al, 1992) which uses an Infrared-based sensor network placed along the ceiling relaying data to a master server. Users are required to wear a badge that emits a unique ID every 10 seconds (or on demand), which are picked up by the sensor network and sent to the server. A similar (and more accurate, albeit more costly) ultrasound-based system is known as Active Bats (Harter et al, 2002), which utilizes ultrasound receiver units placed on the ceiling. The user carries a unit (known as Bat) which contains an ultrasonic transducer and a unique identifier. The signals are then sent to a centralized controller to compute the location and orientation using multilateration (trilateration using added measurements). A significant challenge that ultrasound and infrared based signal solutions face is their inability to transmit signals through walls or floors.

Radio frequency based systems include RADAR (Bahl and Padmanabhan, 2000) which uses a mobile host to broadcast packets (as a beacon) to three base stations (PCs equipped with wireless adapters). Bahl and Padmanabhan (2000) experiment with the following two methods. Firstly, an empirical approach is taken where signal strength values are compared to collected values during an off-line phase and then triangulated. However, a less time consuming approach was then proposed by using the signal propagation model, which is based on mathematically generated theoretical signal strength data. Kotanen et al (2003) describe the Bluetooth Local Positioning Application (BLPA), which converts signal strength indicators to distance estimates, followed by applying the extended kalman filter to determine the position of the user. Chittaro and Nadalutti (2008) experiment with displaying localized 3D route instructions (on a VRML-based 3D model) using RFID technology. Beacon RFID tags are strategically placed within a building which send a signal every 500 milliseconds. The user's position is computed by an RFID reader using signal strength measurements. Mulloni et al (2009) utilize fiduciary markers (or barcodes), which are detected through mobile phone cameras, in order to determine users' position. The position is determined through initially developing a database with location information of the markers on the map.

Another approach is to use existing wireless networks (e.g. Wi-Fi hotspots in a building), which can be less costly as existing infrastructure can be used. Thus, only a software based solution is required (Xiang et al, 2004). An early example, as already discussed, of this approach is RADAR, which was tested in an instrumented environment. Wi-Fi hotspots in urban locations are becoming prevalent, thus removing the need to use additional hardware to achieve positioning. However, due to the irregularities of Wi-Fi signals (caused by multipath effects, where signals arrive using multiple paths), it can be challenging to make an accurate indoor positioning system. Furthermore, Xiang et al (2004) found that factors such a low number of Wi-Fi hotspots creates less accuracy and thus propose using positioning algorithms. To address these challenges, modern Smartphone technology can be used, in particular sensors such as gyroscopes, compasses, cameras, proximity sensors, accelerometers and electromyography sensors (Liu et al, 2012). Kim et al

(2012) demonstrate that in-built Smartphone technologies like accelerometers and digital compasses can be used for dead reckoning techniques to improve positioning. The authors found that signal strength variance is significantly improved using this approach. Xiao et al (2011) experiment with using inertial sensing (using gyroscope, magnetometer and accelerometer sensors) and Wi-Fi fingerprinting to improve positioning accuracy.

It is apparent that there are significant tradeoffs between, for instance, complexity and accuracy of positioning techniques. Generally, using a combination of signal measurements, positioning algorithms (as well as modern Smartphone sensors such as accelerometers, digital compasses, etc) produce more accuracy. For building environments, the pervasiveness of Wi-Fi hotspots in urban areas is promising. Companies such as Google have already released their indoor maps feature which exploits this approach.

2.2.4 Context-Awareness

Context-aware computing (Schilit et al, 1994) has sought to address the various changes in the user's environment that mobile computing instigates. Schilit et al (1994) defines three aspects of context: where you are, who you are with, and what resources are nearby. Furthermore, the authors describe context as including "lighting, noise level, network connectivity, communication costs and bandwidth, and the social situation". The authors also describe four different techniques of providing context-aware information. These include proximate selection, automatic contextual recognition, contextual information on commands and context-triggered actions. Proximate selection involves the idea of a user interface emphasizing nearby located objects (e.g. devices and places) to make them easier to choose. Automatic contextual recognition involves replacing components or changing connections with components due to changes in context. Contextual information on commands reflects on location changes to show relevant information to the user. Finally, context-triggered actions refer to pre-specified rules that need to occur when the context changes.

A common application of context-awareness for the purposes of navigation is supporting tourism (e.g. in museums). An early example is the Cyberguide application (Abowd et al, 1997), whose design was driven by supporting visitors at the Graphics, Visualization and Usability (GVU) center at Georgia Tech. The system was designed using a component based approach, which provided services similar to tour guide roles. These include cartographer (information about the environment), librarian (information about interesting sights), navigator (positioning component to determine user location), and messenger (e.g. to send a message to the owner of an exhibit). The application combined these functionalities and ran on a mobile device (Apple MessagePad). Another pioneering example is the GUIDE system, which was developed by Cheverst et al (2000) as a tour guide. The GUIDE application was utilized through a Fujitsu TeamPad and during a field study in Lancaster, United Kingdom, users were able to retrieve information about locations, navigate around the city using a map, create and follow a tour of the city, communicate with other visitors or the tourist information centre through text messaging, and book accommodation. Graham and Kjeldskov (2003) describe the notion of indexicality, which is defined as an interface representation that has context-specific meaning. The authors describe a context-aware mobile service (e.g. this could run on a PDA), Trammate, which aids users to plan routes and helps show only context-specific information (by determining user location) and with access to the user's digital calendar.

Graham and Cheverst (2004) propose a number of paradigms which are useful in context-aware applications. Firstly, the "Guide" acts as a decision support system which can make recommendations and other assistive information. The "Local" is an information repository (e.g. a local expert) of the current location. The "Chaperone" paradigm involves "looking after" the user, for instance, if the user is doing something wrong (e.g. wrong turn). A "Buddy" offers cooperative and intelligent support, using elements from the Local and Guide. Finally, the "Captain" provides information similar to turn-by-turn instructions in a vehicle navigation system. Cheverst et al (2001) outline some challenges that must be considered for context-aware systems. For instance, the expertise of the user needs to be considered to avoid unpredictability. In a critical situation, for instance, the user must be able to trust the system to appropriately adapt to a context and provide the correct support.

2.2.5 Location Modelling

Location models are a key component in location-aware and context-aware systems. Models are required to provide information about distances between objects, ranges (objects contained within a specific area) and orientation (Becker and Durr, 2004) based on stored representations. Location information can be presented in two formats: geometric coordinates and symbolic coordinates. Coordinates of objects are part of a formalized coordinate system, for instance, GPS utilizes the WGS84 standard to express location as geographic longitude, latitude and elevation above sea level. Alternatively a local multi-dimensional coordinate system can be defined, for instance, a building environment can utilize a planar or three-dimensional Cartesian reference system. The benefit of geometric coordinates is that they allow quantitative calculations of distances between locations. One can determine if two areas overlap, touch each other or if one area contains another (Becker and Durr, 2004). Geometric coordinates can be global (used to define coordinates anywhere on the planet) or local (specific to a location). Symbolic coordinates, on the other hand, use more user-friendly notation (e.g. floor number, room number, etc.) which is more meaningful and human readable. Information such as distances, however, can only be qualitatively determined and quantitative measurements need to be explicitly defined.

2.2.5.1 Requirements

Requirements for location models are typically centred on the ability to provide information about position, distance and range (Becker and Durr, 2004). The position of mobile and static objects such as users, buildings, and rooms is a common requirement for location and context aware systems (Hohl et al, 1999; Becker and Durr, 2004; Satoh, 2007). Satoh (2007) stresses the importance of position especially in pervasive environments, which might contain multiple computing devices such as embedded computers, PDAs and public terminals. These devices can provide application-specific services and can be moved from place to place by users, and must therefore be represented in the location model. Position can be represented using coordinates, and location models must be able to support different coordinate reference systems (e.g. global WGS84 used by GPS, or a local coordinate system based on 3D Cartesian coordinates). The notion of distance is important, if for instance, a user wishes to find the nearest restroom to his current location. However, in some cases, paths might not be suitable for all pedestrians (e.g. a wheelchair user) and the closest location might not be the most convenient. Thus, the topological model, or interconnections between neighbouring locations, must be modelled (Becker and Durr, 2004). Location models must also be able to return range queries, that is, the objects within a specific space (e.g. for queries like: what rooms are on the 2nd floor?).

The requirements must also fit into the application scenario, that is, a location model must address application-specific and environmental constraints. Kray et al (2008) describe the requirements for a location model designed to support indoor navigation using public displays and mobile devices. The authors outline a set of requirements, which fit into both

Becker and Durr's (2004) proposals, but also requirements that are specific to the application scenario. For instance, the public displays are situated to specific locations with fixed orientations. The location model must be able to support the representation, orientation and position of the display infrastructure. Furthermore, building environments generally contain multiple levels, thus the location model must also be able to support the three-dimensionality of the space.

2.2.5.2 Symbolic Models

There are three approaches to developing symbolic location models, including the set-based model, hierarchical model, and graph-based model. Set-based models use set notation to describe the environment. For example a floor in a building can be represented by a set *L*, which contains all the rooms on this floor: L_{floor1} = {R1, R2 ... R5}). Set-based models are useful for determining range queries, for instance, overlapping locations by calculating the intersection of two sets. Limitations of this model involve its high modelling effort and that distance data is qualitative. The Active Badge system (Want et al, 1992), for instance, uses symbolic identifiers of infrared sensors that register the unique ID emitted by user badges. The system enables users to determine their current position; however, distances are not supported. The GUIDE system (Cheverst et al, 2000) uses location objects (e.g. gallery, castle) which contain HTML-based page references that include attributes such as opening times and other related information. Position is communicated through base stations that broadcast location messages to the mobile GUIDE units.

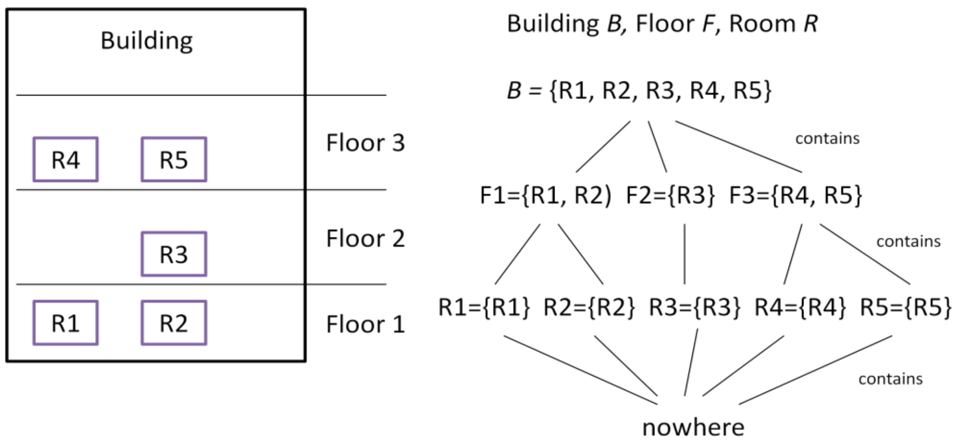

Figure 1 - Hierarchical location model example.

A hierarchical approach involves using a lattice or tree structure (see Figure 1) to model locations and the inclusion of other locations. Figure 1, for instance, is a simple example that represents a building *B* with five rooms on three floors and a tree-based hierarchy. Lattices are used when overlapping areas need to be modelled. The bottom of the hierarchy represents rooms, followed by the floor and the building (top). We can qualitatively represent distance by the notation d(R1, R2) < d(R1, R3). However, this qualitative representation of distance does not contain the geometric length, nor does it account for factors such as a shorter and more direct link (e.g. staircase) between R2 and R3. This would mean the distance between R2 and R3 would be shorter.

A graph-based model includes symbolic coordinates that are represented by vertices. An edge is added if there is a direct connection between two vertices, which can be weighted in order to model distances. This model supports topological relations "connected to" and also explicit distance definitions between symbolic coordinates. Thus, nearest neighbour and navigation-related queries are supported. An example of a graph based model is described by Jensen et al (2009), where each partition in a building floor plan is represented by a vertex (e.g. a single room, staircase, hallway, etc.). Edges are represented as connections between vertices, such as a door, hatch or a window. Jensen et al (2009) present an RFID-based positioning system which is based on the described graph based location model. The approach consists of deploying the RFID readers so that an object cannot move from one cell (partitioned indoor space) to another without being detected. The RFID readers contain an activation range (between 10cm to 3m) so that when an RFID tag enters the range, the readers are then able to detect it.

Combining the graph-based and the set-based approach produces the optimal solution as distances can be quantitatively determined from the graph (i.e. through edge or vertex weight) and range information is supported through set notation. Becker and Durr (2004) state that using both models has many benefits, but a trade-off is the modelling effort required to model two location models. The authors anticipate that applications that require both range and nearest-neighbour queries would be designed to provide large-scale functionality across many applications, thus the effort of this model would be justified.

2.2.5.3 Geometric Models

Indoor spaces can be modelled as a mesh of polygons, whose vertices can be represented using geometric coordinates (e.g. placed on an arbitrary set of coordinates with a user-defined origin). A benefit of this approach is that distances can be determined through defined geometric positions. The Yamamoto system (Stahl and Haupert, 2006), for instance, utilizes both a symbolic and geometric modelling approach. Here, the geometric aspect of the system is discussed to aid the description of this approach. The Yamamoto system is designed to be a map modelling toolkit for supporting pedestrian navigation within intelligent environments (e.g. equipped with positioning sensors such as RFID, IR and Wi-Fi access points). A new model of an environment (e.g. a building) can be created by scanning an architectural floor plan as a bitmap and using a graphical editor to draw polygons to represent, for example, rooms, corridors, etc. The system also allows navigational fixpoints to be added through primitive shapes like circles, points and sections. These fixpoints can be used to represent Wi-Fi access points, active RFID tag locations, and other positioning-related technologies. However, as discussed below, geometric models are often combined with symbolic models, which provide more user-friendly descriptions (e.g. compared to informing the user about the length of the next route segment and the angle of turn).

2.2.5.4 Hybrid Models

A hybrid model combines both symbolic and geometric coordinate information (Becker and Durr, 2004) and thus, the benefits of both approaches can be utilized. If, for instance, a location model requires higher accuracy and precise distance queries, it is necessary to integrate a geometric model, as a symbolic model will only provide qualitative distance information. Lyardet et al (2008) describe the CoINS navigation system, which uses a location model that combines symbolic graph-based models with geometric models. The symbolic model allows the system to communicate room numbers, corridor names, floor numbers, etc. in a human readable way. The geometric model facilitates a key subcomponent of the system, which is pathfinding. Similarly, systems such as Yamamoto (Munzer and Stahl, 2007) and PerPosNav (Schougaard et al, 2012) utilize hybrid models in order to facilitate and optimize navigation related queries.

2.2.6 Experimental Context-aware and Location-aware Platforms

NEXUS (Hohl et al, 1999) is an early example of an infrastructure designed to aid the development of location models to support context-aware applications and scenarios where users might require navigation support. The system proposes the notion of augmented areas, which consist of general objects in the geographical region, NEXUS system installations and information content. The environment is represented as an Augmented

Area Model, which can consist of several interconnected augmented areas. The model enables every object (mobile, stationary and virtual) of interest in the augmented area to have a data structure that represents the object's state. The data can be stored, for instance, in a digital library or on the World Wide Web. Client services and applications can be attached with sensor systems (e.g. GPS sensor), which can be used to provide information about the object state in the physical world. An example scenario is described in the context of a conference building, where all visitors, items and rooms are represented in the augmented model. The position of every object can be determined, for instance, through infrared. Thus, a visitor can find a person through using a navigation application on their mobile device.

The COMPASS system (Kargl and Bernauer, 2005) utilized a plug-in based approach that enabled flexibility such that multiple positioning technologies (e.g. Wi-Fi access points, RFID, accelerometers, digital compasses, etc) can be utilized to determine user location. The motivation behind this is that sensor technologies are sensitive to error (e.g. Wi-Fi can suffer from multi-path effects), thus, by using a combination of technologies, errors can be reduced. The system is able to translate geometric coordinates into semantic (or symbolic) descriptions, which is more meaningful for users. To calculate position, a probability distribution function method is used with a two or three-dimensional Cartesian coordinate system.

Satoh (2007) describes a location model framework for developing and managing context-aware services. A component-based approach is used, involving a virtual counterpart component (digital representation of entities such as a person, object, building, room, etc), an aura component (to represent the scope surrounding an entity), a proxy component (that enables communication between the location model and digital device), and a service component (provides application specific services for places and entities). A navigation scenario is envisaged where a user with a mobile device (e.g. PDA) enters a building and is able to view a map of their current position through various RFID readers in a building that are managed by the location management system (LSM). The LSM then tries to discover the component bound to the PDA, informs the virtual counterpart of the room and the relevant service module is forwarded to the PDA. The PDA then refers to this module to display a map of the room.

PerPosNav (Schougaard et al, 2012) is a combination of methods and services designed to support custom indoor navigation applications that can be developed on a variety of platforms. PerPosNav is built on top of the authors' earlier work with the PerPos (Blunck et al, 2010) platform. PerPos is designed to provide a variety of cloud-based services (e.g. Sensor Fusion for enabling position technologies to supplement each other, Behaviour Recognition for recognizing behaviour patterns from position and motion data) for positioning and location-based applications. The location model service provided by PerPos combines a symbolic and geometric approach. This approach enables PerPos to support a graph searching algorithm based on Dijkstra's algorithm (Dijkstra, 1959) and is able to generate a navigation graph with decision points as nodes connected by segments. PerPosNav also enables the integration of multiple positioning technologies, such as Wi-Fi, Infrared, RFID combined with in-built Smartphone sensors such as accelerometers and digital compasses.

2.2.7 Review of Indoor Navigation Systems

This section provides a discussion of indoor navigation systems in published literature. The systems are compared based on the components described in section 2.2.1. An overview is provided in Table 1, which shows the ways in which indoor navigation systems have utilized route communications, client devices, positioning, context-awareness, and location models. Furthermore, we identify the systems which have undergone user evaluation and systems which have been developed as proof-of-concept. Firstly, Table 1 below provides an overview of indoor navigation systems. Indoor navigation systems that have been developed for cognitively impaired users such as Drishti (Ran et al, 2004) and for emergency conditions have been omitted as they are not within the scope of this thesis.

Table 1 – Overview of indoor navigation systems published in literature.

(CA = Context-aware; LM = Location model; SLM = Symbolic location model; CLM = Combined location model; GLM = Geometric location model; HLM = Hybrid location model; POC = Proof of concept)

System	Route presentations	Devices	Positioning	CA	Evaluation	LM	Algorithm
Cyberguide (Abowd et al, 1997)	2D map, text	PDA, Pen-based PC	Infrared	Yes	POC / informal feedback	No	No
CricketNav (Miu, 2002)	2D map	PDA	Ultrasonic	No	POC	Hybrid	Dijkstra
IRREAL (Baus et al, 2002)	3D visualization	Smartboard, Palm Pilot	Infrared	Yes	POC	No	No
GentleGuide (Bosman et al, 2003)	Vibration	Wearable wrist device	Wizard of Oz	No	User study	No	No
BPN (Kruger et al, 2004)	2D map, 3D, audio	PDA, PC	Infrared	No	POC	Hybrid	Dijkstra
GAUDI (Kray et al, 2005)	Graphical arrows, text	Situated displays	Configured	No	POC	Combined	A*
Rotating Compass (Rukzio et al, 2005; Rukzio et al, 2009)	Graphical arrows, vibration	Public display, mobile phone	Configured (2005), GPS (2009)	No	User study	No	No

System	Route presentations	Devices	Positioning	CA	Evaluation	LM	Algorithm
Open-SPIRIT (Rehrl et al, 2005)	2D map, text	Mobile phone	Bluetooth	No	POC	Hybrid	Multi-modal
Smart Signs (Lijding et al, 2006)	Graphical arrows, text	Public display, handheld device	Configured	Yes	User study	No	No
3DVN (Elmqvist, 2007)	Augmented reality wire-frame	Wearable PC, head mounted display, glove	Wi-Fi	No	Field study	No	No
Chloe@University (Peternier, 2007)	Augmented reality	Head mounted display	Wi-Fi, RFID	Yes	POC, performance study	Geometric	A*
iNav (Kargl et al, 2007)	2D map, text, spoken audio	PDA	COMPASS (Kargl and Bernauer, 2005)	No	POC	Hybrid	A*
PerPosNav (Schougaard et al, 2012)	Augmented signs, 2D map, audio, AR	Mobile phone, projectors	RFID, Wi-Fi, dead-reckoning	No	User study	Hybrid	Dijkstra

2.2.7.1 Route Presentations

It is evident that a variety of digital route presentations have been utilized across the indoor navigation systems presented in Table 1, including maps, 3D representations (IRREAL and BPN), graphical arrows (GAUDI, Rotating Compass and Smart Signs), text (Cyberguide, GAUDI, Open-SPIRIT, Smart Signs and iNav), audio (BPN, iNav and PerPosNav), vibration (GentleGuide and Rotating Compass), and augmented reality (Chloe@University, 3DVN and PerPosNav). Maps (or floor plans), graphical arrows, and text were the most widely used. As previously discussed in section 2.2.1.3, maps are the most commonly used resource for assisting navigation. Furthermore, text-based instructions do not require sophisticated applications for development, and graphical arrows are known to require lower cognitive costs (Holscher et al, 2007). It is also clear that route presentations in all systems used a combined approach, such that no route presentation is shown on its own. The GentleGuide system only used vibration-based instructions, however Bosman et al (2003) anticipate that graphical displays would need to be combined in order to support users across more complex routes.

The indoor navigation systems presented in Table 1 have either been developed as proof-of-concept (Cyberguide, CricketNav, IRREAL, BPN, GAUDI, Open-SPIRIT, Chloe@University and iNav) or have undergone preliminary user evaluations (Cyberguide, GentleGuide, Rotating Compass, Smart Signs, 3DVN, PerPosNav). Some insights were provided by the evaluated systems, however these are mainly preliminary and more rigorous evaluation is required to meet user needs for route presentations. The GentleGuide system revealed that using vibrations as instructions on wrist devices was intuitive for users. The Smart Signs system, which utilized public displays to show context-aware graphical arrows (coupled with text), was compared to existing printed signage in a university building. Lijding et al (2006) found that users performed better using the Smart Signs, and also favoured the system in terms of learnability, helpfulness, efficiency, and satisfaction.

Rukzio et al (2005) found that users were positive towards the use of the Rotating Compass system, which combined the use of public displays (showing personal graphical arrows) and a mobile phone used for vibration prompts. Another, and more detailed, study using the Rotating Compass was carried out in 2009 (Rukzio et al, 2009) comparing the use of a paper map, mobile phone map, display only and synchronized display and phone. It was found that users favoured the use of the display-only and synchronized condition (although more effort and mental demand were required, compared to the paper map and phone map conditions). Elmqvist et al (2007) carried out a field study with the 3DVN system and found that users were impressed with the system, albeit concerned about the worn equipment.

The PerPosNav system was designed as a combination of services and methods for supporting indoor navigation. Schougaard et al (2012) evaluated some initial prototypes based on PerPosNav. Their first evaluation involved using projected signage in a hospital environment and revealed promising feedback from users. A second evaluation in a shopping mall was carried out involving a mobile map application and revealed that users expect a precise representation of their location (as the application was slightly imprecise).

2.2.7.2 Client Devices

In terms of client devices, most navigation systems used mobile devices (PDAs, head-mounted displays, mobile phones and mobile sensors) to display and communicate route presentations. Whilst early systems involved PDAs (e.g. Cyberguide, CricketNav, BPN), modern Smartphones (e.g. as utilized by PerPosNav) provide benefits through sensors such as accelerometers and digital compasses in order to optimize positioning. A constraint with mobile devices, as found in Rukzio et al's (2009) user study, is that users tend to pay less attention to the environment. Similar behaviour has been observed by Muller et al (2008) in their user study. GentleGuide and the Rotating Compass systems have experimented with mobile devices as a medium for prompting users through vibration to carry out actions (e.g. turning with GentleGuide and to follow a graphical arrow on a display with the Rotating Compass). However, complex route information cannot be communicated through vibration alone. Head-mounted displays are explored by 3DVN and Chloe@University where augmented reality-based approaches were used to display annotated virtual navigation aids (arrows) overlaid on the view of the physical environment. Whilst interaction with the environment may be more natural, wearing extra equipment can be a concern for users (e.g. users may not be prepared to accept wearable computers as fashionable).

Public displays were used by the IRREAL, GAUDI, Smart Signs and Rotating Compass systems and evaluations carried out by Smart Signs and the Rotating Compass revealed that users found it useful to view, for instance, graphical arrows on the displays. A benefit of digital signage like graphical arrows, is that they can be adapted to provide personalized support (Smart Signs, Rotating Compass) adapt to physical re-locations (GAUDI) and provide opportunistic support for events (GAUDI). The IRREAL navigation system uses Smartboards (or large public displays) as a means of displaying three-dimensional representations of the user's environment (which can also be viewed on a PDA). However, the advantage here is that users are able to utilize a larger display. Situated projectors, as investigated by Schougaard et al (2012), introduced another interesting means of display route presentations (e.g. graphical arrows). Projectors have the flexibility to display on multiple surfaces (e.g. wall, floor or ceiling).

2.2.7.3 Positioning

Earlier indoor navigation systems such as Cyberguide, CricketNav, IRREAL and BPN experimented with using infrared and ultrasound-based positioning. Whilst positioning accuracy can be adequately achieved (approximately 50cm with CricketNav), the requirement for additional hardware and the line-of-sight limitations of infrared and ultrasound can be limiting factors. Cyberguide, IRREAL and BPN also utilized proximity-based positioning techniques whilst CricketNav used multilateration. With developments and wider availability of radio frequency-based technology, Bluetooth (Open-SPIRIT), Wi-Fi (3DVN, Chloe@University) and RFID (Chloe@University) have been utilized by later systems. The Open-SPIRIT used a proximity-based positioning technique with Bluetooth, which is optimized (to handle propagation) by using a data model that contains information about the Bluetooth beacons (e.g. sequence, hierarchy). Chloe@University, which used both Wi-Fi and RFID uses a number of positioning techniques. For Wi-Fi, the system used a fingerprinting method where a signal data map is created from wireless access points in the off-line phase. RFID signals are triangulated in order to determine position, rather than relying simply on proximity and signal strength approaches.

Systems such as iNav and PerPosNav utilized a more adaptive approach where multiple positioning technologies (e.g. Wi-Fi, RFID, etc) could be used. For instance the COMPASS system used by iNav enables the system to use position data received through multiple sources, thus enabling greater positioning accuracy. Similarly the PerPosNav system also enables the use of multiple positioning technologies combined with dead-reckoning, for instance, through the use of a Smartphone's in-built accelerometer and digital compass sensors.

Public displays used by GAUDI, the Rotating Compass and Smart Signs were used to show graphical signage (through graphical direction arrows coupled with relevant textual information). The public displays used by GAUDI, for instance, were able to display the appropriate graphical arrow, destination location and distance to destination by communicating with a navigation server. The Smart Signs and Rotating Compass system detects user proximity by using Bluetooth (Rotating Compass) and sensor-based approaches (Smart Signs) and is able to determine the individual user's destination location to show the appropriate graphical arrow. Thus, the displays can themselves be described as the positioning tool (Huang and Gartner, 2012) for users.

2.2.7.4 Context-Awareness

Navigation systems such as Cyberguide, IRREAL, Smart Signs and Chloe@University have taken contextual factors into account. Cyberguide utilizes a very basic form of context-awareness, that is, by determining user position and orientation (or positioning, as discussed in the previous section). Information about exhibits was viewed through user-selection rather than automatic. IRREAL is able to adapt from being used outside (ARREAL) when the mobile device received infrared data. Route instructions are generated by taking into factors such as the user's cognitive resources and mobile device's display capabilities (e.g. screen size, colour capabilities). The Smart Signs system provides personalized route instructions to users, and is able to factor in aspects such as the user's mobility limitations, weather conditions and emergency situations. Chloe@University is able to adapt to deviations that users might make en-route (i.e. route re-calculation functionality) as well as determining areas of interest that surround the user.

2.2.7.5 Location Models and Route Calculation

Route calculation (e.g. using Dijkstra's algorithm or A*) requires either a graph-based, combined graph-based and set-based, geometric, or a hybrid location model (Becker and Durr, 2004). It is evident from Table 1 that all of the navigation systems which have utilized location models (i.e. CricketNav, BPN, GAUDI, Open-SPIRIT, Chloe@University, iNav and PerPosNav) have also used routing algorithms.

2.2.7.6 Summary

The development of digital indoor navigation systems is a complex task that must take into account ways of presenting route instructions using appropriate client devices, achieving positioning, and addressing contextual factors. It is clear that each of these components is also associated with a variety of challenges. Existing indoor navigation systems in published literature have experimented with a variety of these components, however, most of these systems have been designed as proof-of-concept and few have undergone user evaluations (which have also been preliminary studies) in order to investigate user interaction requirements.

2.3 Chapter summary

This chapter has reviewed past literature in the domain of indoor navigation. From this review we have identified: (1) the fundamental challenges with indoor wayfinding, (2) the challenges of integrating various digital components in indoor navigation systems, and (3) the ways in which existing indoor navigation systems have addressed these challenges. It is clear that research concerning indoor navigation systems have mainly focused on establishing functionality feasibility. While this is an important aspect, it is also necessary to develop indoor navigation systems that closely address the needs of users and form a deeper understanding of the systems' context of use. Using the methods reviewed in section 2.3, we aim to address the gaps in past research, and provide a better understanding of user requirements and contextual factors in order to aid the development of indoor navigation systems.

The next chapter describes the approach utilized in this thesis and provides a background to the methods which we have adapted in our design (user-centered design and prototyping) and analysis (grounded theory and activity theory).

Chapter 3

Approach

By examining the review provided in the previous chapter, it is evident that indoor navigation systems have mainly been evaluated in terms of functionality and system performance. Although functionality is an essential facet for the development of indoor navigation systems, designing a system that is tailored towards the needs of users requires a different strategy. In order to address this gap in literature, the research described in this thesis has sought to utilize a more user-centered approach by carrying out formative user studies, during which we aimed to uncover qualitative insights relating to user interaction preferences, requirements, motivations, and patterns of use. In addition, research into the ways in which existing digital resources within modern buildings can be utilized to support visitor navigation is also limited. For example, it is clear that Wi-Fi access points are becoming prevalent in urban locations, thus removing the need for installing existing infrastructure to achieve positioning in building environments. Similarly, we believe that non-navigation specific technologies within buildings, such as public displays, can be useful resources for providing navigation support. The Hermes2 deployment in the Infolab21 building provided an opportunity to investigate the potential of exploiting an existing display infrastructure for supporting visitor navigation.

This chapter firstly reviews the methods which are relevant to the research of this thesis. Following this, we describe the ways in which these methods have inspired and driven our research.

3.1 Methods

The methods utilized in this thesis involved user-centred design, prototyping, formative user studies, and analysis using grounded theory and activity theory. The development of indoor navigation systems involves a wide variety of interconnected technologies which must be seamlessly integrated in order to provide useful and usable navigation assistance to users. It is essential to establish the functional feasibility of the various components that are integrated in navigation systems. Norman and Draper (1986) suggest that functionality is a primary consideration in the design of an interface and to ensure that the system essentially "works". However, it is also important to design systems that are appropriate and tailored to the needs of the users. With interactive systems in mind, Rogers et al (2011) state: "While they may work effectively, it can be at the expense of how the system will be used by real people". Indoor navigation systems must take into account the needs of its users as well as the complex social dynamics that can exist within indoor spaces. For instance, public, semi-public and private spaces can all be contained within one building environment. Furthermore, as this thesis addresses the suitability of adapting an existing situated display system (i.e. Hermes2) for the purposes of navigation, the navigation system must address the needs of an additional set of users and practices that are established around the existing system. Therefore, it is not only important to gain insight towards user interaction, but also examine and understand the context of use.

3.1.1 User-Centered Design

Gould and Lewis (1985) recommend three key principles for designing useful and usable interactive systems. Firstly, it is necessary to involve users at an early stage, and to use their tasks and goals as the driving force behind the development. Secondly, empirical measurements can be used to observe user reactions and performance through developing system prototypes (discussed in the next section). Finally, the reactions from using the prototypes must be observed, recorded, analyzed, and then formulated into an iterative design process, which involves cycles of design, test, measure, and redesign. Interestingly, when Gould and Lewis (1985) first proposed their ideas, they were regarded as obvious by developers. A survey involving system planners, designers, programmers and developers revealed, however, that the above three principles were effectively overlooked by most of the participants and the design principles that were regarded as "common sense" were not fully understood by designers. Although the notion of User-Centered Design (or UCD) was not discussed in this context, these principles have become the basis of UCD (Karat, 1997; Rogers et al, 2011).

UCD is regarded as more of a philosophy, which can be described as a "coherent set of principles that guide a designer on individual projects" (Norman and Draper, 1986), rather than a technique for system design (Rogers et al, 2011). Norman and Draper (1986) reflect on UCD and provide insights such as: "let the requirements for the interaction drive the design of the interface, let ideas about the interface drive the technology". Karat (1997) stresses the significance of extending the design of a system from the usability of an interface to also including its suitability in its context of use. UCD may not be strictly defined, however, the principles it presents are essential in guiding the design of an interactive system. One must also question: to what extent should users become involved? Rogers et al (2011) survey a few examples of UCD motivated projects where involving users has been a positive move, whereas others have involved more negative outcomes. For instance, Subrayaman et al (2010) found that developers and users were most satisfied with a moderate level of participation (i.e. 20% of project development time). It is therefore argued that a balance needs to be maintained in terms of the level of user participation.

3.1.2 Prototyping

"A prototype can be anything from a paper-based storyboard through to a complex piece of software..." (Rogers et al, 2011). A prototype of a system can enable designers to explore ideas, aid communication between team members and also discuss ideas with its stakeholders. Thus, it can be viewed as an important technique for UCD. The importance of prototyping can be observed in the following description by Rogers et al (2011): "It is often said that users can't tell what they want, but when they see something and get to use it, they soon know what they don't want". Prototyping involves collecting information about work and everyday practices along with views about what a system should and should not do, and then iteratively building prototypes to try out design ideas (Rogers et al, 2011). Dix et al (2004) describe three main approaches to prototyping, which are described below:

- **Throw-away:** A throw-away prototype is one which is discarded after being used to gain design knowledge to inform the build of the final product.
- **Incremental:** In this case, the final product is incrementally built as separate components. Whilst there is an overall design for the final product, it is partitioned into smaller components.
- **Evolutionary:** Here, the system is seen as "evolving" from a limited initial version to its final release.

Prototypes can be low-fidelity or high-fidelity. Low-fidelity prototyping may not resemble the final product, however, they are low-cost and easily modifiable, which is important especially during the early stages. Low-fidelity prototyping techniques involve the following:

- **Sketching and storyboarding**: storyboards are arrangements of sketches that depict the behaviours of design elements (Landay and Myers, 2001) and shows how a user might progress through a task using the product under development (Rogers et al, 2011). Sketches (e.g. hand-drawn) can help visualize the functionality of the system under development. Sketches can be applied to storyboarding, for instance, as frames.

- **Wizard of Oz:** Wizard of Oz (or WoZ) prototypes derives from the classic story of the little girl who finds herself in the Land of Oz The Wizard is a man who is hidden and operates an artificial image of himself. Here, the functionality of a system is mediated through a human user which enables the system user to carry out certain tasks.

In contrast, high-fidelity prototypes utilize materials which are expected to be used in the final version of a system. For instance, a prototype based on a Java program has a higher fidelity than a paper-based sketch. Both high and low fidelity approaches contain trade-offs. For instance, Retting (1994) suggests that high fidelity prototypes are time consuming, reviewers end up commenting on superficial issues, and developers are prone to resist changes. On the other hand, the system has the look and feel of the final product, more functionality and serves as a living specification (Rogers et al, 2011). Similarly, low-fidelity prototypes have less functionality but are low-cost and useful for identifying requirements. Nevertheless, prototyping enables the involvement of users from an early stage and the generation of design ideas through evaluation that need to be recorded and analyzed. The findings from the evaluations need structure, and in the next sections, theoretical frameworks including grounded theory and activity theory are introduced. These frameworks aid in structuring gathered data and in providing insights towards the design and development of interactive systems.

3.1.3 Formative User Studies

The research presented in this thesis utilizes formative user evaluations with data gathering techniques such as semi-structured interviews, questionnaires, think-aloud, and observation (Rogers et al, 2011). Formative evaluation typically involves an iterative process of ensuring the usability of interactive systems by including users throughout the development phase (Rogers et al, 2011; Hartson et al, 2001; Gabbard et al, 1999). By using this evaluation approach, we were able to adhere to the User-Centered Design approach described in section 3.1.1 of this chapter. The next step following formative evaluation is generally considered to be summative evaluation (Rogers et al, 2011), however, as the prototype navigation system was not designed to be a fully functional end-product, only elements of summative evaluation were incorporated. Hartson et al (2001) state "sometimes formative usability evaluation can also have a component with a summative flavour". An important aspect of user evaluations is the level of control that is applied to the setting (Rogers et al, 2011). For example, controlled settings include laboratory-based studies where users' activities are controlled to test hypotheses and measure certain behaviours. On the other hand, natural settings (e.g. in public spaces) involve little control of users' activities in order to determine how the product would work in the real world. Rogers et al (2011) suggest that both types of settings have benefits and shortcomings; controlled settings yield better usability data, whereas natural settings are good at demonstrating how people use technologies in its intended setting. The research in this thesis aims to utilize a natural setting to carry out the formative user evaluations with a certain level of control. This is further discussed in section 3.5 of this chapter.

3.1.4 Grounded Theory

Rogers et al (2011) describe grounded theory as "an approach to qualitative data analysis that aims to develop theory from the systematic analysis and interpretation of empirical data, i.e. the theory derived is grounded to the data". The approach was developed by Glaser and Strauss (1967). Grounded theory can also be described as a "general methodology" which enables theories to involve continuous interplay between analysis and data collection (Strauss and Corbin, 1994). The process of grounded theory involves alternating between data collection and analysis (Rogers et al, 2011). Firstly, data is collected (e.g. by carrying out an evaluation) and analyzed to identify categories, which then leads to the need for further data collection, and so forth. This pattern continues until no new insights emerge. The notion of coding is central to grounded theory, which involves marking up data according to emerging categories. According to Straus and Corbin (1998), coding has three aspects:

- **Open coding:** This involves the process through which categories, their properties and dimensions are discovered by analyzing data. Coding can exist in different granularities, such as at the word, line, sentence and conversation level.
- **Axial coding:** This process involves relating categories to their subcategories.
- **Selective coding:** Once the categories have been formulated, selective coding can be applied to refine the categories and form a larger theoretical scheme.

Rogers et al (2011) suggest ways of aiding the process of stimulating the analyst's thinking to identify and characterize categories. These include questioning data and considering different ways of looking it, analyzing words, phrases or sentences to trigger different perspectives on the data, and using comparisons between objects and abstract categories that would enable alternative interpretations to emerge.

3.1.5 Activity Theory

Activity theory derives from Soviet psychology developed during the 1920s, which consists of a research framework and a set of perspectives designed to explain human behaviour in terms of our practical activity with the world (Nardi, 1996; Rogers et al, 2011). The origins of activity theory are also related to the works of Leont'ev (1974) as part of Marxist psychology. The objective of activity theory is characterized by Nardi's (1996) description: "activity theory is a powerful and clarifying descriptive tool rather than a strong predictive theory. The object of activity theory is to understand the unity of consciousness and activity". Activity theory enables an understanding into context, situation and practice, thus making it important for Human Computer Interaction (HCI) research. The use of technology extends further than a mechanical input-output relationship between person and machine and a much richer depiction of the user's situation is needed for design and evaluation (Nardi, 1996).

Activity theory consists of six underlying interrelated principles, which are summarized by Kaptelinin (1996). The first principle concerns the *unity of consciousness and activity* and that the mind can be analyzed and understood only within the context of an activity. The second principle is *object-orientedness*, which specifies that our activities are directed towards objects, which have physical, chemical, cultural and social properties. These properties in turn shape the way in which we interact with objects. The third principle is the *hierarchical structure of activity*. For instance, each activity can be hierarchically represented as *actions* (behaviours that require conscious planning) and *operations* (routine-like behaviours that require little conscious attention). At the top of the level is the *activity*, which provides meaningful context for understanding actions. The relationship can be further extended by *motives* that elicit activities, *goals* that guide actions, and the *conditions* that are necessary to carry out operations to achieve goals. The importance of these distinctions can be exemplified by considering that people behave differently in different situations of frustration. For instance, when a goal is subject to frustration, a new goal must be defined. This hierarchical model is illustrated in Figure 2.

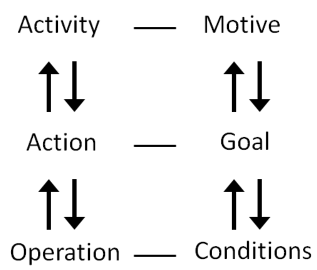

Figure 2 - Hierarchical activity model.

The fourth principle is *internalization-externalization,* which suggests that mental processes are derived from external actions through the course of internalization. In other words it can be argued that human activities are distributed and re-distributed in the internal and external domains. Kaptelinin (1996), for instance, suggests that human beings acquire new abilities from "inter-subjective" and "intra-subjective" mental actions. Externalization refers to the mental processes which manifest themselves as external actions. The fifth principle is *mediation*, which is described as the ability to utilize external components, such as tools, in order to perform a new action or perform an existing one more efficiently. Rogers et al (2011) define mediation as "a fundamental characteristic of human development is the change from a direct mode of acting on the world to one that is mediated by something else". Finally, the sixth principle involves *development,* which suggests that in order to understand, for instance, a phenomenon, it is necessary to know how it developed into its existing form. Thus, development involves observing the changes over time.

The activity theory model aids in structuring the interconnected relationships between *object*, *subject* and *community*. Kuutti (1996) defines *object* as a physical/material thing, something less tangible like a plan, or something completely intangible like an idea. Objects also follow the idea of mediation. The model also involves a *subject* who performs an activity. Kuutti (1996) describes an additional component known as *community*, which represents members who share the same object. Thus, the subject, object and community form the basis of this model. The relationships between the three notions have been further extended by Engeström (1987) by representing the *division of labour* (between object and community and as a means of classifying the labour in a workplace), *rules* (between community and subject, representing the set of conventions and policies shared by members of a community), and *tools* (which is a means of mediating between the subject and object). Finally, transforming the object into an outcome motivates the existence of the activity (Kuutti, 1996).

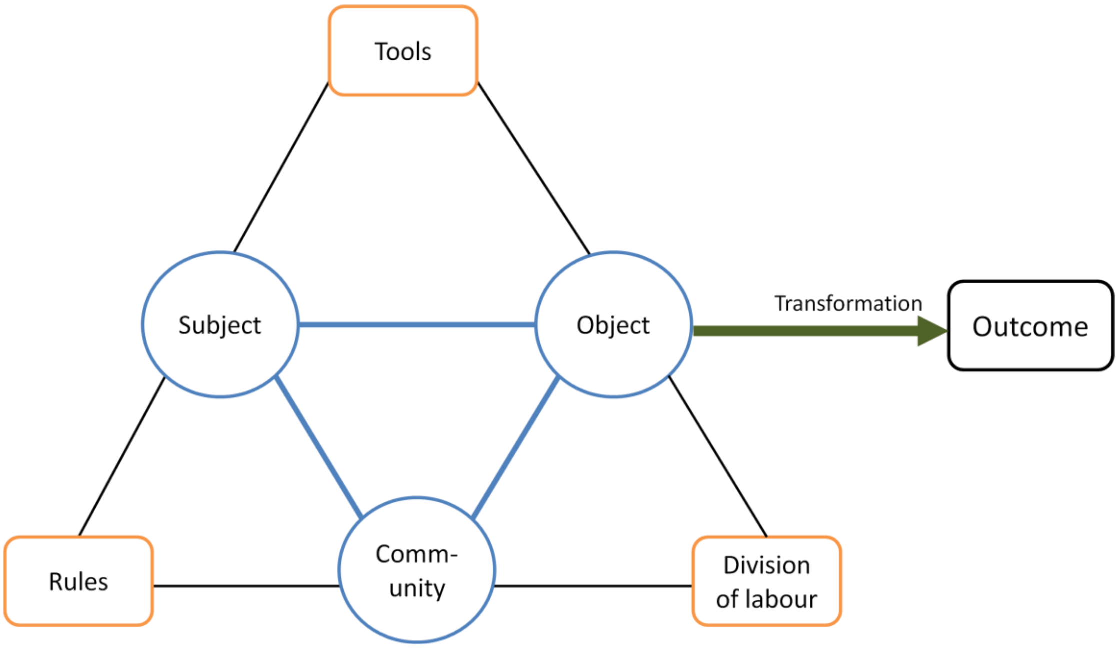

Figure 3 - Engeström's activity system model.

3.2 Research Approach

The approach in this thesis adapted the methods described above by utilizing a user-centered approach that was combined with prototyping, formative user studies and analysis that is inspired by grounded-theory and activity theory. In order to address the first two research questions described in section 1.2, six formative evaluations (5 user studies and 1 questionnaire study, see Table 2) were carried out involving 62 participants. Although the overall approach used in the user studies was not amended, specific changes that were made for each study are detailed in chapters five, six, and seven. Here, an overview is provided (see Table 2). The third research question described in section 1.2 was tackled through longitudinal observations, experiences, and by logging important activities (e.g. technical issues, monitoring activities, and display owner requests) of the Hermes2 deployment.

The first study expanded on a preliminary study (Taher, 2008) and focused on investigating user motivations, interaction preferences and requirements for the combined use of route presentations (i.e. maps and 3D route visualizations), user attitudes towards using personal mobile phones for navigation, and the overall feasibility of the prototype navigation system. The development of the prototype navigation system was during its early stages, therefore the functionality of the system in the first study was limited (i.e. the Hermes2 situated displays were not investigated). Nevertheless, it was important to establish the utility of the system and the route presentations in order to motivate further research and development. Similarly, a second questionnaire-based study expanded on initial insights provided by Kray et al (2006) to explore display owner attitudes towards using the Hermes2 deployment for navigation purposes. This questionnaire study helped motivate the first research question tackled in this thesis.

The third user study built on the first two studies by including the Hermes2 deployment as part a formative user study to explore the feasibility of integrating the Hermes2 deployment and its messaging application for the purposes of supporting visitor navigation. Therefore, the prototype navigation system was further developed to integrate the Hermes2 deployment (to a limited extent). The third study re-visited investigations towards the combined use of route presentations and mobile phone use, and the study also explored the user interaction preferences, requirements and user attitudes towards using the situated displays and the messaging application.

Due to limitations encountered in the third study and insufficient understandings on the usefulness of the Hermes2 display interaction, a short (fourth) user study was carried out to explore user interaction preferences and requirements towards situated displays and personalized graphical signage (i.e. directional arrows). The fourth study helped ensure the utility of the Hermes2 displays and the messaging application for the purposes of supporting visitor navigation.

The fifth study utilized a more rigorous approach by addressing limitations in previous studies, and investigated the interactional aspects of all the components of the Hermes2 navigation system (i.e. mobile phones, situated displays, and route presentations). Study six expanded on the fifth study by examining the system's context of use, as well as the potential of providing multi-user and location-aware support using a combination of mobile phones and situated displays.

Table 2 - List of user studies and the research questions addressed.

Study #	Type of study	Key objective	Research question	Chapter
1	User study (follow-on to preliminary study)	Interaction preferences for the combined use of route presentations and mobile phone use.	1	5
2	Questionnaire	Display owner attitudes and preferences towards adapting the Hermes2 system for navigation support.	2	6
3	User study	Interaction preferences for mobile phone use, combined use of route presentations, and Hermes2 deployment.	1 and 2	6
4	User study	Interaction preferences for the use of the Hermes2 deployment.	1 and 2	6
5	User study	Interaction preferences and requirements for using the Hermes2 navigation system.	1 and 2	7
6	User study	Contextual implications and exploring multi-user/location-aware support using the Hermes2 navigation system.	1 and 2	7

Each study was designed to focus on specific but overlapping objectives. The Hermes2 navigation was prototyped such that additional functionality was incrementally developed in order to meet the objectives of each study. The data from observations and discussions were then analyzed in terms of our general study objectives, as well as by using a grounded-theory approach to gain further insights into emerging themes. The findings were also structured using activity theory, for instance, by using activity models to represent the key findings. The general research approach process is depicted by Figure 4. Each study procedure was also re-examined to address inconsistencies and limitations in order to refine the process for the next study.

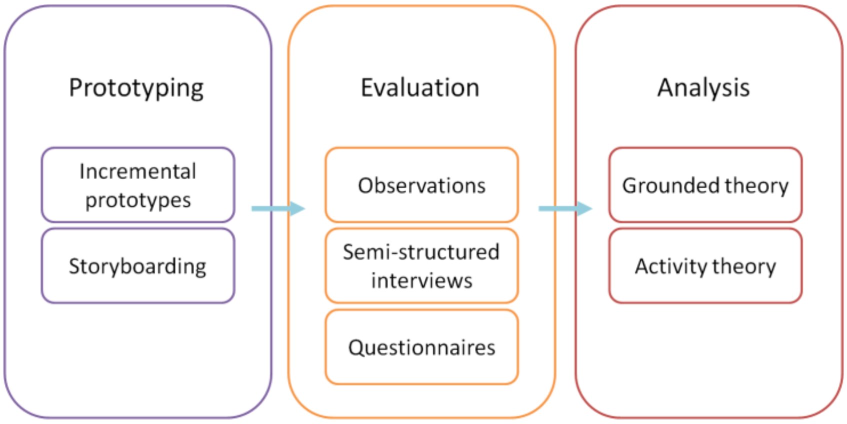

Figure 4 – The general approach used in our research.

3.3 Initial Design Stages

Prior to the work carried out in this thesis, the development of the prototype Hermes2 navigation system underwent several design stages (Taher, 2008). To summarize, these included carrying out preliminary interviews to motivate system development by, for instance, asking users what aspects of a digital indoor navigation system would be useful. The next stage involved identifying the requirements for the proposed prototype, including the purpose and goal of the system, the functional and non-functional requirements, and so forth. Following this, the system was conceptualized with higher-level functionalities, leading to illustrating the tasks involved during system use (by creating a Hierarchical Task Analysis) and finally, specifying the detailed and more lower-level architectural properties of the system and its component relationships.

During the development of the prototype, several informal evaluations were carried out in order to receive feedback towards the appearance of the graphical user interface (e.g. button size, terminology, layout, etc.) and to anticipate any functional problems. Furthermore, usability evaluations were carried with the prototype system by engaging in discussions with expert evaluators. Such evaluations were essential in identifying common issues with the graphical user interface such as the layout, appearance and size of the buttons and labels, terminology, and the task processes that users must undergo while using the user interface.

3.4 Prototyping

The approach to prototyping the Hermes2 navigation system involved incremental modifications that augmented its functionality to suit the objectives of our user studies. Storyboards were also utilized in order to inform the procedure of the user study and to visualize the ways in which users would interact with the prototype system. An example of a storyboard, utilized for study five, can be found in Appendix E.1. As the navigation system was not deployed over a long period of time, it was not within the scope of our work to fully implement the system to the level of a final and polished product. The functionality of the navigation system was only used during the user evaluations, thus it was not necessary to enable dynamic route computations for all locations in the building. The rationale behind the limited use of the navigation system is discussed in section 3.5.1. It was important, however, to ensure that the prototypes were sufficiently functional in order to enable study participants to successfully complete tasks as well as enable us to receive useful insights. Thus, the prototypes served as a means of gathering ideas and insights from users in order to build an understanding of requirements, preferences, motivations, usage patterns, and context of use that would benefit designers of similar indoor navigation applications.

3.5 Evaluation

The formative user evaluations aimed to study the prototype navigation system in its intended setting, as opposed to a purely lab-based approach. We also aimed to recruit participants who had no prior experience of the building. The general study procedure involved asking study participants to sign a consent form, become familiar with the navigation system components (e.g. the kiosk display, viewing route presentations, using the mobile phone), carry out tasks (e.g. locate a specific building occupant), and then walk to their destination, using the navigation system. We aimed to expose users to the components of the navigation system to gain insights into interactional and social issues. This was typically followed by a semi-structured interview that consisted of in-depth discussions with participants regarding their experiences, preferences and requirements. Demographic data was collected using questionnaires, and observations were recorded through audio and video. Participants were asked to use a combination of route presentations and displays (i.e. mobile phone and Hermes2 displays) as we aimed to create a realistic setting that would provide insight into the ways in which users utilize and react to various technologies. An alternative method would involve evaluating user interaction with the route presentations and displays individually, however, this would have been more time consuming and would not have provided us with the qualitative insights that can be achieved by observing users in a more naturalistic setting.

The user studies were ecologically valid to a certain degree. Whilst we did not create lab-based conditions to control all facets of the study (Rogers et al, 2011), the task based approach, as well as the notion of participating in a study, was inevitably bound to influence behaviors of the participants. The tasks carried out by study participants were designed to be as unobtrusive as possible. Rogers et al (2011) discuss that this approach contains certain limitations where it becomes difficult to anticipate which features of a system are going to be used. These issues were handled such that if a specific feature of the navigation system is unexplored, the next study introduced more control and participants were asked to interact with the feature.

3.5.1 Deployment Concerns

Although the Hermes2 system and its messaging application were fully deployed, the navigation functionality was only used for the purposes of the formative user studies. The methods used in the studies were mainly sufficient in developing an in-depth understanding of users, however, a more ecologically valid approach to the user studies would have involved carrying out a longitudinal study of actual visitors (rather than recruited participants) by deploying the prototype navigation system. The challenges relating to the deployment involved a number of factors. The process of incremental prototyping, evaluation and data analysis was time-consuming. Several unanticipated hardware related issues experienced with the Hermes2 deployment further affected the potential of deploying the navigation system. In addition, the deployment of this system raised concerns with the receptionist and their role within the building (e.g. directing visitors to their destinations is part of a receptionist's responsibility).

3.6 Analysis

The data collected from the formative evaluations was transcribed (i.e. the audio/video recordings) and a grounded-theory based strategy was applied where the transcripts underwent coding in order to form categories that were both relevant to the objective of each study, as well as to any unexpected findings that emerged. These categories were used to develop qualitative insights (which were also supported by quantitative data) towards the interaction preferences, requirements, behaviors, and contextual factors surrounding the use of our navigation system. The analysis of data from each study also aided us in determining which aspects of the navigation system required further exploration, thus providing implications for the next study.

To further support our user-centered design approach, we utilize ideas from the framework presented by activity theory and analyze sets of activities with our system in order to develop an understanding of users, objects and context from our observations and data. The underlying principles of activity theory, such as internalization/externalization, mediation, object-orientedness, and development over time offer a means of rationalizing user motives towards the use of our prototype navigation system. This approach is particularly relevant as the system integrates the Hermes2 display deployment, which is already associated with a set of social practices with its original messaging application. We utilize activity theory by formulating activity models based on user study findings in order to present a set of insights that are relevant for the design and development of indoor navigation systems (e.g. in chapters five, six, and seven).

3.7 Reflection of Selected Methods

The user-centered approach utilized in our research differs in comparison to related approaches such as feature-driven development (Highsmith and Cockburn, 2001), where the focus is producing deliverable systems in a timely manner. The aim of our approach is, however, to aid the understanding of users and the ways they interact with the different elements of the Hermes2 navigation system by evaluating incremental prototypes. This approach perhaps slows down the development process of a functional system, however, an indoor navigation system involves a number of complex mechanics based on the interaction with various technologies, as well as the contextual elements of its deployment environment. Past research (as described in chapter two) has already demonstrated the potential of various technologies and proof-of-concept navigation systems, but whether users will find these systems user-friendly and usable in various building environments requires further investigation (and has thus motivated the research in this thesis).

The formative user studies were designed to be carried out in a natural setting but with controlled conditions, that is, the navigation system was used in its intended environment but users were given tasks. Carrying out studies in natural settings can be advantageous for gathering data such as user behaviours and patterns of use. However, as Rogers et al (2011) indicate, evaluation in natural settings can cause unexpected user behaviour and leave elements of a system unevaluated. Thus, we progressively observed the elements of the navigation system that were overlooked by users in each study and introduced further control in the following study procedures such that all elements were eventually utilized. A fully ecologically valid approach would require an ethnographic study (Rogers et al, 2011) involving a functional and deployed system where users could be observed in real-world scenarios (rather than carrying out tasks in a study). However, due to deployment concerns stated in section 3.5.1 of this chapter, as well as using incremental prototypes, an ethnographic study was not feasible and the ecological validity of our approach was limited.

During each formative user study, the data gathered was maximized through combining techniques such as think-aloud, semi-structured interviews, direct observation and questionnaires (Rogers et al, 2011; Dix et al, 2004). Although this approach can produce a large set of qualitative data, some techniques may not feel natural for study participants (e.g. when participants were asked to think out loud whilst carrying out a task). Therefore, there is a compromise between the ability to gather important data such as a participant's thought process, and how naturally they are able to carry out tasks. Similarly, study participants may be affected in the way they carry out their tasks if they are aware of being observed. Techniques such as semi-structured interviews are useful in that it allows for useful discussions that provide detailed insight into user opinions and attitudes.

Furthermore, questionnaires can aid in gathering additional data to assist qualitative assertions with quantitative data.

Grounded theory and activity theory (as described in sections 3.1.3 and 3.1.4 in this chapter) were combined such that grounded theory and its coding technique aids in developing coherent interpretation from large sets of qualitative data (e.g. transcripts from interviews) and activity theory aids in organizing the findings as a framework. Alternative techniques would have involved frameworks such as distributed cognition or situated action models, however, activity theory was more suited to our research due to its adaptability and its core concepts that revolve around the subject, object, and community. For example, these can represent the interconnected relationships between the user and his/her objective of finding a location in an environment which has an existing set of practices. The situated action model framework is more focused on the immediate situation, and Nardi (1996b) state that situated action models are less effective for generalization and comparison. Distributed cognition bears similarities to activity theory (Nardi, 1996b) in that it is directed towards achieving an understanding of a collective effort when carrying out tasks, shared between individuals and objects. However, the framework for activity theory is richer than that of distributed cognition (Nardi, 1996b).

3.8 Chapter Summary

This chapter firstly reviewed the methods used in our research and revealed the importance of involving users in the design process, as well as the theoretical frameworks that can aid the analysis and understanding of data collected through evaluation. Whilst these methods are not strictly adhered to, they are used as a guide in order to closely involve users in our research. We then described the ways in which these methods were utilized as part of our work, namely in a series of formative user evaluations.

The next chapter describes the experimental configuration, that is, the components surrounding the Hermes2 navigation system.

Chapter 4

Experimental Configuration

In order to address the gaps in the literature reviewed in chapter two and the approach described in the previous chapter, the prototype Hermes2 navigation system was developed and evaluated in our formative user studies. The navigation system integrates a number of components and a general overview is as follows:

- The Hermes2 display deployment, which was originally designed to support a messaging application.
- Additional devices to aid navigation, such as a touch-screen kiosk style display and personal mobile phones.
- Route presentations including first-person 3D route visualizations, digital 2D maps, and graphical directional arrows.

During each formative user study, parts of these components were modified in order to meet the requirements of our investigations. The specifics of these changes are discussed in the next three chapters. Here, we initially provide a description of the environment in which the navigation system was utilized. Next, a technical description of the Hermes2 deployment is provided, including the functionality of its messaging application. Following this, the components related to the navigation application are presented with justifications of design decisions, methods of development and a description of the system architecture.

Finally, we describe the experiences, challenges and responsibilities of managing the Hermes2 deployment.

4.1 Infolab21 Building

The Infolab21 building (Figure 5) is located on the Lancaster University campus and integrates a technology oriented office-based environment consisting of academic departments such as the School of Computing and Communications, as well as a commercial business based department known as the Knowledge Business Centre (KBC). It provides support for research and development, education and training as well as businesses. The building architecture consists of four different floors with roughly F-shaped corridor design. Visitors in the building can currently receive navigation assistance by seeking directions from the receptionist and using on-the-wall printed graphic and text-based signage (e.g. Figure 5).

Figure 5 - (left) The Infolab21 building, (middle) on-the-wall printed signage, (right) temporary signage near the entrance.

One of the scenarios that the Hermes2 navigation system aims to address is providing assistance to visitors during occasions where the receptionist is unavailable (e.g. if they are helping other visitors). A brief discussion with the receptionist revealed that “people normally come straight to the reception, although it’s usually people who are friendlier. Once they come here once, the next time they usually find their way on their own". However, the receptionist is also responsible for other tasks such as delivering mail to various parts of the building. Therefore, there are several occasions where the receptionist is unavailable (e.g. this was observed over four years). Another scenario that the navigation system aims to address involves directing visitors to temporary events (e.g. Figure 5). Currently, temporary printed signage is required in order to direct visitors to such events. Using a digital approach would, for instance, reduce the need for printing and also enable a more dynamic approach if the events become re-located.

4.2 The Hermes2 Deployment

The Hermes2 system adapted the idea of sticking a note on a door saying "Gone for coffee..." or "Back in 5 minutes..." and was designed to support awareness in a work environment (Hudson and Smith, 1996; Dourish and Bly, 1992) through these messages. The first version of the digital display system known as Hermes (Cheverst et al, 2003; Fitton, 2006) was deployed in 2002 as PDAs, which were situated adjacent to office doors of lecturers, administrative staff, research assistants and PhD students, all members of the Computing Department (now known as the School of Computing and Communications) at Lancaster University. In 2006, the department moved to a newly constructed building (i.e. the Infolab21 building) and new set of digital display prototypes were deployed, known as Hermes2.

The design of Hermes2 was informed by evaluation (such as semi-structured interviews, questionnaires and informal conversations in the work environment) of the previous system. Several hardware modifications and improvements were included in Hermes2, such as larger seven inch displays. The Hermes2 deployment was completed in May 2007 and consisted of forty displays in two separate corridors on two floors. Six of the displays were designed to be used by groups of users, mainly between PhD students and research assistants, and 34 displays were designed for academic and administrative staff members. The displays are placed adjacent to office doors on a transparent surface (see Figure 6). Display owners (or office occupants) are able to control whether passers-by can look inside their offices by opening and closing the blinds.

Figure 6 - The deployment environment in the Infolab21 building.

4.2.1 Functionality

The primary users of the Hermes2 displays (i.e. display owners) are able to set a temporary text or multimedia message to show on their display using their personal web portal, by using SMS on a mobile phone or via e-mail. For example a display owner may set a photograph of a conference location followed by text underneath: "At Germany for Mobile'HCI, back on the 15th". Display owners are also able to view messages left by visitors using their personal web portal and well as through e-mail. Visitors are able to leave text-based messages using an on-screen keyboard, and scribbled messages. For instance, Sarah may find that a staff member is away and leave a message "Hi it's Sarah, came to see you at 1.15pm..." by using an on-screen keyboard. Thus, the functionality is designed to be shared between display owners and visitors.

4.2.2 Hermes2 Messaging Application

Two versions of the Hermes2 messaging application have been developed and are based around a Model-View-Controller architecture. The *Model* involves a MySQL database, which stores data such as display owner details. The *View* includes the graphical user interface, and the *Controller* provides functionality for the messaging application.

The first version has been designed and developed to be highly customizable (to support student research projects, etc.) and consists of middleware that provides services such as access to configuration information and software components that provide functionality (Fitton, 2006). This was designed to allow users to securely add or modify components of the system. The Hermes2 architecture is Java-based on the client-side (the graphical user interface) and the server is responsible for running the Hermes2 clients and messages set by display owners as well as visitors (Cheverst, et al 2007). The server also hosts a MySQL database, which stores information based on component configuration, owner preferences and system logs (e.g. actions carried out by users on the GUI).

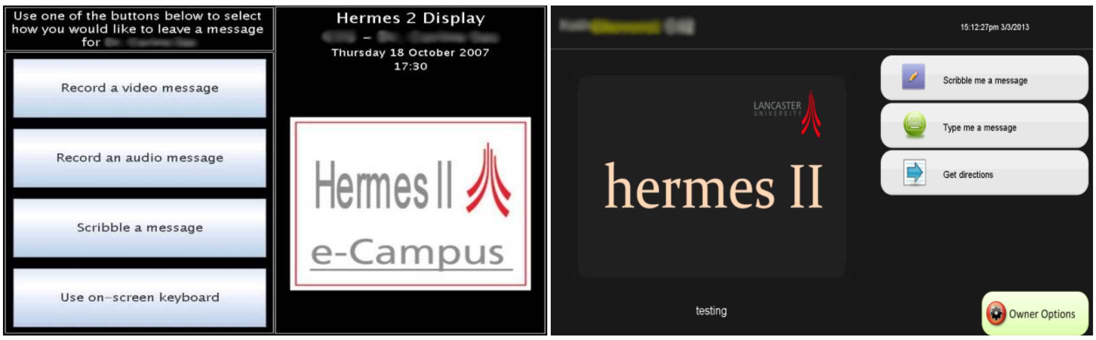

Figure 7 - (left) Java version of the Hermes2 messaging application, (right) the ASP.NET based version.

The second version is a web-based AJAX application developed in ASP.NET, which combines C# server-side functionality and is hosted on a separate Windows Internet Information Services (IIS) server. In this thesis, the second ASP.NET based version of the

Hermes2 messaging application is focused on because the majority of management and support of the deployment involved the .net version of the application. This version was developed as an experimental version of the Hermes2 messaging application in mid 2009 in order to enable rapid prototyping as well as allowing cross-platform functionality (i.e. any device with a web browser can run the application). The client-side incorporates Javascript, ASP.NET, XML, HTML and WCF as a communication layer. This version of the Hermes2 application has similar functionality. However, users are not able to leave audio messages or video-based messages, as the logs revealed that these features were not being sufficiently used by visitors.

The Hermes2 application uses a component-based model in order to enable users to easily add components (e.g. the navigation application component). The application architecture is shown in Figure 8. Each component typically contains a view, which consists of HTML, ASP.NET, and JavaScript. The controller uses C# and is responsible for the functionality of the view. The roles of services are as follows.

- The *navigation listener* is used to handle navigation-related queries to enable, for instance, the situated displays to show appropriate route presentations.
- The *monitoring service* enables administrators to view the current status of connected clients (i.e. displays that are running the messaging application).
- The *logging service* logs useful activities such as when a display owner sets a message or when there is an application error.
- The *error notification service* sends out an e-mail to administrators when an error is detected.

- The *scribble messaging* and *keyboard messaging* services are used to process the text and scribble messages to generate files that are uploaded to the Hermes2 server.

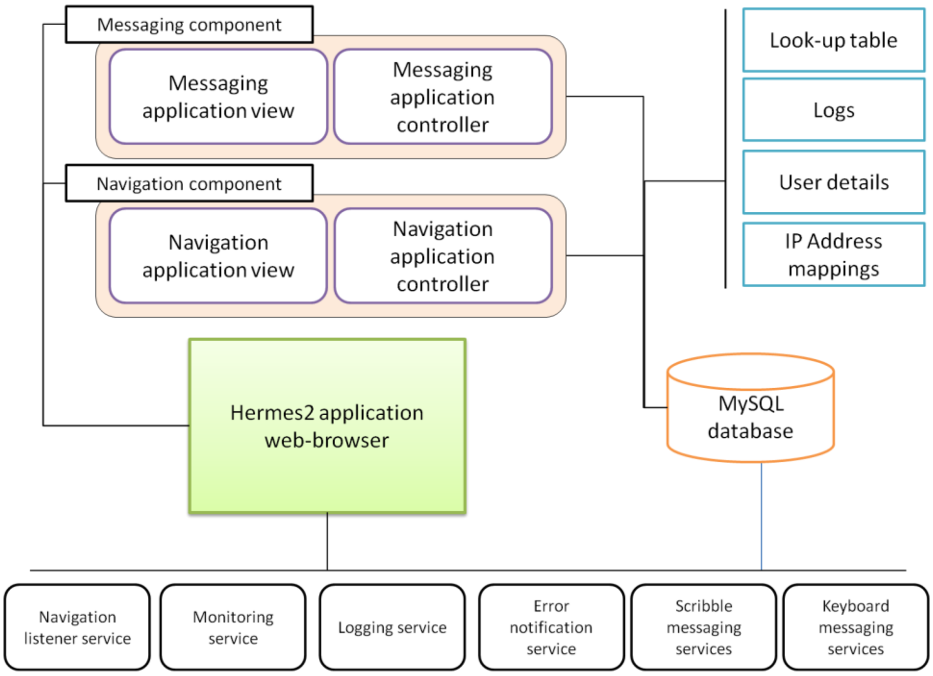

Figure 8 - Client-side architecture of the Hermes2 system, which integrates both the messaging and navigation application.

4.2.3 Technical Description

The hardware of the Hermes2 system involves the 40 digital displays, which are connected with power, graphics (i.e. VGA), and Ethernet cabling to a single-board computer (SBC) under the floor (i.e. through removable floor-boards). The SBCs are powered using Power over Ethernet (POE), which is handled by nine midspans located in a separate machine room in the Infolab21 building. The midspans are connected to an Ethernet switch, which enables communication between the Hermes2 central server and the midspans. There are two types of network, one of which is a private network involving the Hermes2 display network, as well as the Hermes2 central server, which can handle external connections. The architecture of hardware components is shown in Figure 9 below.

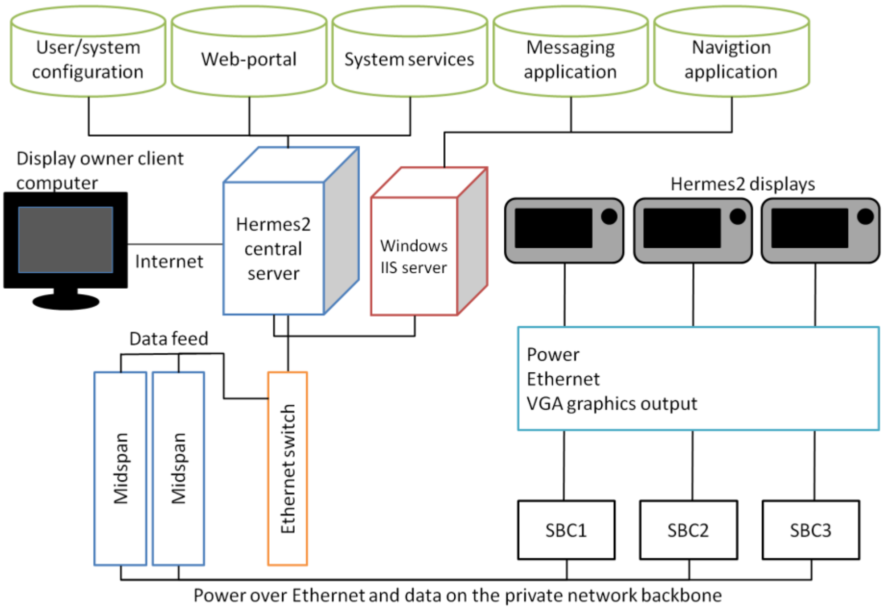

Figure 9 – Architecture diagram of the network of devices that are integrated in the Hermes2 display deployment.

The Hermes2 server is Linux-based and enables data management through a MySQL database (e.g. user configurations) as well as services and file repositories for the Hermes2 application. As the operating system is not stored locally on the SBCs, the Hermes2 system utilizes a NetBoot process, such that each SBC connects to the Hermes2 server on startup and loads a disk image. The boot process is illustrated in Figure 10 below. Once the SBCs are powered on (e.g. through a cron script that programmatically connects to the midspan interface), they send out requests to a DHCP server which resides on the Hermes2 server. The DHCP configuration file then sends the address of the boot server, the file-path and an IP address for a specific display. The SBCs then send a request for a bootloader (e.g. pxelinux) to the TFPT server (also on the Hermes2 server). After the bootloader is sent, it is used to retrieve the kernel image, boot parameters, and the location of the image. Finally, the SBCs send out a request to mount the NFS fileshare to be able to use the disk image.

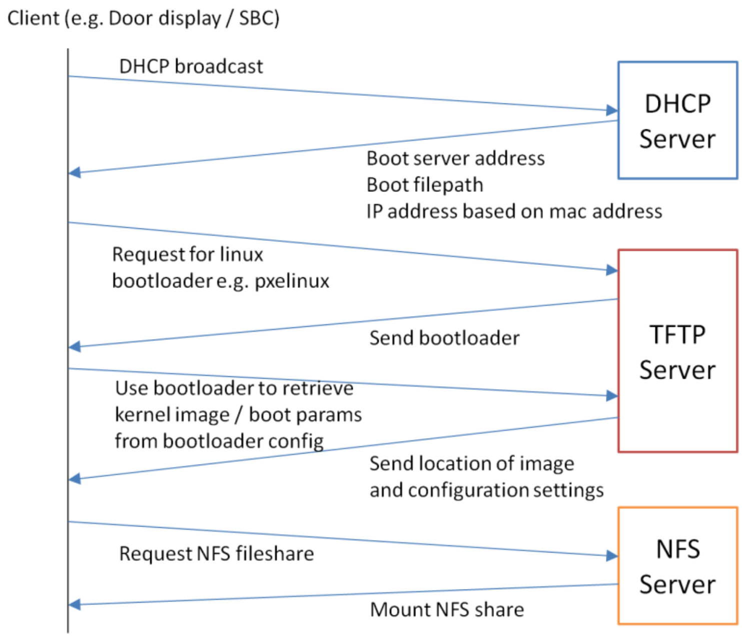

Figure 10 - Boot process of a Hermes2 display.

Each SBC contains a configuration file that enables it to load a web-browser on startup. As each SBC has a unique IP address, the .NET client application utilizes the IP address as a parameter and retrieves the appropriate database entries for that particular display (e.g. display owner name, current messages set, etc.).

4.3 The Hermes2 Navigation System

The prototype navigation system was designed to be integrated with the Hermes2 system as an additional application component. The navigation component further integrated mobile phones, a touch-screen kiosk display, and route presentations. The development process, including design decisions, is described below. As the prototype underwent interface design modifications to reflect added functionalities investigated in the user studies, a general overview is provided here and the modifications are detailed in chapters five, six, and seven.

4.3.1 Hermes2 Navigation Application

The Hermes2 navigation application involved a graphical user interface (GUI) that was designed assist users to locate their destination location. More specifically, the GUI enabled users to carry out the following tasks:

- Search for building occupants (e.g. a staff member) who are represented through photograph-based icons.
- View the message they have set on their displays, through integrating functionality from the messaging application (e.g. "Back in 5 minutes").
- Receive directions to their location by viewing route presentations that show the route from their current location to their destination.
- "Take-away" the route presentations on a personal mobile phone (e.g. by downloading the presentations using Bluetooth).
- Request navigation assistance (e.g. through graphical directional arrows) from the situated displays whilst en-route.

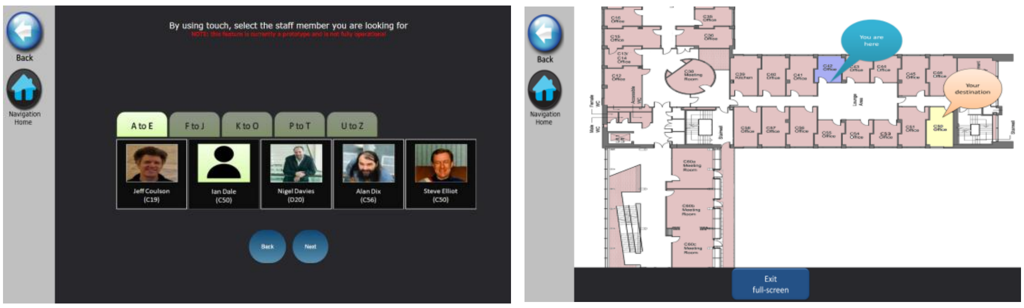

Figure 11 - (left) the graphical user interface of the navigation application, (right) a view of a map using the application.

Similar to the Hermes2 navigation application, the initial version of the navigation application was developed using Java in 2008, and detailed in (Taher, 2008). However, in order to suit the messaging application's shift from Java to ASP.NET, the navigation application GUI was re-implemented using ASP.NET in 2009. The messaging application was integrated with the navigation application such that users could view display owner messages through the navigation application GUI. This decision was based on providing awareness to visitors early in their navigation task (i.e. as opposed to finding out that an office occupant is away once they have walked to their office). The navigation application GUI was also designed to be used on the situated displays. For instance, users might want directions to a location whilst they are stood outside a display owner's office. Figure 12 below shows the devices that are part of the navigation system.

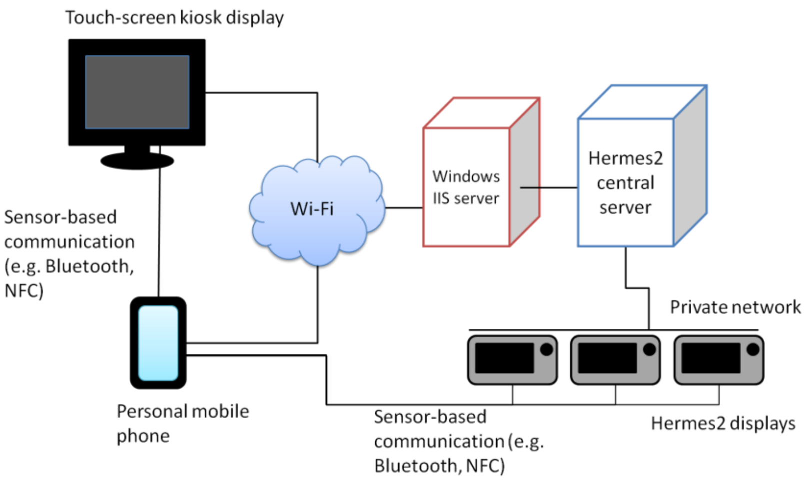

Figure 12 - Client devices involved in the Hermes2 navigation system.

The navigation application was also designed to be used on a large touch-screen kiosk display placed next to the reception area near the entrance to the building. We envisaged that the kiosk display used would serve as a reference and information point for visitors who have just entered the building, where they could determine the whereabouts of a building occupant and receive directions to their office. This was partly motivated by discussing visitor conduct with the receptionist, who stated that most visitors walk towards the reception desk upon entrance, for example, to request directions. Digital kiosk displays are also prevalent within a variety of buildings, such as shopping centers, train stations, airports, and so forth.

4.3.2 Route Presentations

The route presentations, such as the first-person 3D route visualizations and digital 2D maps, enabled the navigation application users to view directions to their destination location from their current location.

4.3.2.1 Digital 2D Maps and Graphical Signage

The use of maps was motivated by their pervasive usage in supporting navigation, as well as their ability to provide survey knowledge (Siegel and White, 1975). It is also evident from the review of past research in chapter two that interaction preferences and requirements for maps in the context of indoor navigation are under-explored. The digital maps were developed using Computer Aided Design (CAD) software, such as Inkscape, and presented as image files (i.e. PNG). They were annotated to show the user's current position, their destination, and their route through a dotted line (e.g. see Figure 11). Furthermore, we used a forward-up orientation to display the map on the kiosk display and the situated displays. The usefulness of a forward-up orientation has been previously explored by Shepard and Hurwitz (1984). For the purposes of our evaluations, a number of map files were stored on the Hermes2 server. Specific numbers of files varied for the purposes of our evaluations, which are detailed in the forthcoming chapters. The routes were pre-configured rather than dynamically computed (e.g. by using a geometric location model).

The motivation behind using the graphical signage (e.g. arrows) relates to their prevalent use for navigation, as well as the low cognitive cost required to follow a sign (Holscher et al, 2007). Similar to the maps, these were also developed with CAD software. As there are a limited number of directions in a building environment and to meet the objectives of our user studies, it was necessary to generate three graphical arrow files (right, left and turn-around).

4.3.2.2 Three-dimensional Visualizations

Past research has shown that 3D route presentations provide transferrable route-finding knowledge into the physical world (Ruddle et al, 1997) as well as enabling users to directly experience the environment, which in turn allows them to develop a sense of familiarity. Unlike maps, 3D presentations are relatively under-explored in the context of indoor navigation systems, as reviewed in chapter two.

The 3D model used in our navigation system was developed by using GtkRadiant[7] and by using the Quake 3 game engine. In more detail, we developed a 3D model of a specific section of the Infolab21 building (i.e. the reception area and the School of Computing and Communications department on the next level). The model was then compiled into .BSP format and run on Quake 3. GtkRadiant was used due to its open-source implementation, which allows flexibility in terms of bug-fixes, modifications and so forth. The textures applied to each structure (e.g. office doors) were composed of photographs that were previously taken inside the Infolab21 building, which were then converted to Quake 3 compatible files. This allowed the environment to appear salient in terms of colour, form and appearance. Using the 3D modeling tool also enabled us to enlarge office door signs to facilitate navigation for users and allowing each office to be clearly identifiable.

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[7] http://icculus.org/gtkradiant/ (last accessed 17th March, 2013).

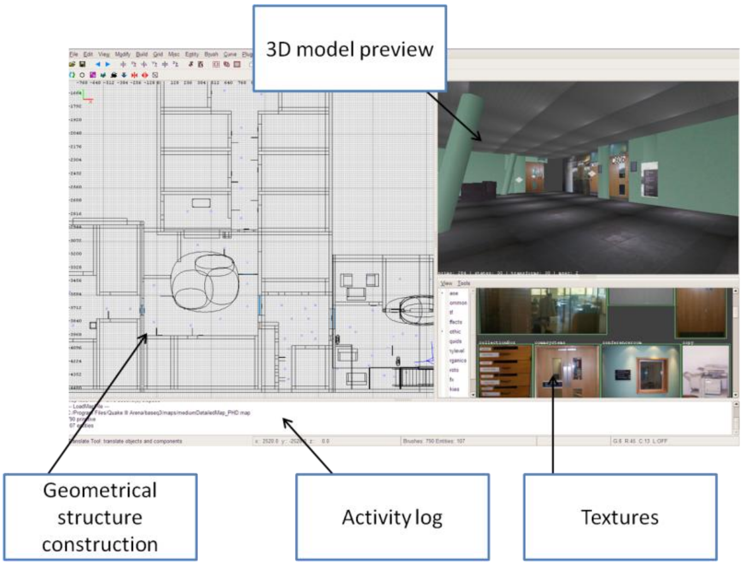


Figure 13 - GtkRadiant development environment showing the various panels

The 3D route visualizations shown on the navigation application were generated by recording (using an in-game recording program named Fraps[8]) the Quake 3 character walking from one location to another (e.g. from the foyer area to a staff member's office). Similar to the maps, it was necessary to generate a number of visualization files, which were stored on the Hermes2 server. The number of files and the duration of the visualizations are specified in the forthcoming chapters.

4.3.3 Route Generation

As route presentations (i.e. maps, 3D route visualizations, and graphical arrows) were represented as media files, they required filenames that portrayed meaningful symbolic information based on the represented route. For instance, a route that directs users from the reception to an office C30 was labeled "reception_c30". Once a user selects a destination and wants to view a map or 3D route visualization, the navigation application uses the location of the current display and the destination location as parameters in order

[8] http://www.fraps.com/ (last accessed 17th March, 2013).

to retrieve the appropriate file. In addition, a MySQL table was constructed as a lookup table in order to support the display of navigation arrows on the situated displays. For example, users navigating to office C30 from the reception area would mean that all displays that precede this office (e.g. C27, C28, etc) will show the appropriate directional arrow.

4.3.4 Personal Mobile Phones

The motivation for experimenting with personal mobile phones was to enable study participants to "take away" the map and 3D route visualization of their route after using the navigation application GUI (e.g. on the kiosk display, or on a situated display) by downloading the routes to their phone (e.g. using Bluetooth). We utilized a lightweight approach such that the maps and 3D route visualizations downloaded to the phone would be media files. Whilst it remains an avenue of further research to investigate the presentation of the map and 3D route through a mobile phone application, which is commonly used in Smartphones, our approach was designed in order to allow any mobile phone (e.g. non-app oriented) with media playback capability to be able to utilize the route presentations (i.e. any phone with the ability to display images and play video files). We later explore the potential of using mobile phones as an input device to receive location-aware assistance by interacting with the situated displays. This approach is further discussed and evaluated in chapter seven.

4.3.5 Location-awareness

The approach to location-awareness used in the Hermes2 navigation system involved using the situated displays as the positioning tool. In more detail, the aim was that once a user interacts with a display (e.g. through sensors based on Bluetooth and/or Near Field Communication), the navigation application utilizes information such as the user's destination location (by identifying the user through a unique id) and the current location of the display in order to show appropriate route presentations. This is carried out by a navigation listener script (illustrated in the architecture diagram in Figure 8). The user essentially informs the system that "I am here" and is then able to view their current location, destination location, and their route. Investigations and insights into the feasibility of this approach are discussed in chapter seven.

As the navigation system was not fully deployed (as discussed in section 4.4.1), a location model was not fully developed in order to handle queries relating to distances, orientation and/or ranges. Route presentations were displayed with the aid of symbolic and parameterized filenames and programmatically showing the relevant file (or route). A complete location model remains as part of future work.

4.4 Managing the Hermes2 Deployment

The Hermes2 deployment was managed and maintained over a period of four years. This was an important part of our research as the navigation system utilizes the Hermes2 deployment. The observations and activities over a period of four years addressed the third research question described in chapter one. The responsibilities involved are described as follows.

- Logging activity of the messaging application, which included the messages set by display owners as well as visitors.
- Resolving technical issues with the display devices, network infrastructure, as well as issues, concerns, and requests expressed by display owners.
- Logging the state of the display devices on a weekly basis. This involved checking for display hardware issues that were not automated through a software-based service (e.g. issues with the Video Graphics Array, or VGA, chip).

- Re-configuring displays to reflect situations where display owners move or become replaced.

To aid the above responsibilities, software services were developed in order to facilitate logging and notification of errors. In more detail, when a display owner sets a message, information of the display, time, and the message (e.g. text, URL link to the photograph that has been set) is logged in a MySQL table. Similar logs are generated when visitors set a message for the owners. The notification service handled two different types of issues: if a display failed to boot, or if the application encounters an error (e.g. a crash), an e-mail was sent to the administrators. Additionally, a monitoring service was also implemented in order to be able to remotely check the application state of all displays which are online by accessing a web-based interface.

4.4.1 Logging

It was necessary to store various types of logs for the Hermes2 deployment. The logs specific to the application (e.g. setting messages) has already been discussed in section 4.2.3. It was also necessary to keep logs of technical problems and actions that were taken to address the problems as well as any modifications made to the Hermes2 application. These were stored in the form of blog-posts on a Wordpress blog site. The written logging process was started in late 2009 and continued for the following three years. Prior to this, we focused on carrying out user studies (e.g. user study one discussed in the next chapter), therefore we carried out fewer maintenance tasks with the deployment. An excerpt of the logs can be found in Appendix A.1.

4.4.2 Technical Issues

The management of the Hermes2 deployment revealed a number of unanticipated technical issues, which involved overheated Video Graphics Array (VGA) chips, midspan failures, server downtimes, and SBC BIOS issues. An initial issue that was faced involved a lack of power being directed to three door displays. Further issues are described in the next subsections.

4.4.2.1 Overheated VGA Chips

One of the first technical issues that we encountered was in 2009. This issue involved overheated Video Graphics Array (VGA) chips that resided within the displays. This was partly caused by insufficient airflow in the display enclosures, as well as problems in the manufacturing process. Similar complaints were also made by other customers, however, this was not known at the time of purchase. By October 2009, a routine inspection revealed that 10 displays had overheated VGA chips, which were causing classic blurry screens. In October 2010 it was found that 22 displays had this issue.

To address the issue with overheated VGA chips on displays, we explored a set of potential solutions, one of which included switching from VGA output to composite output on the displays. However, due to issues with cabling and a lack of a manual for the SBCs, this was not a viable option. Another option was to reorganize the structure of the deployment such that a specific area of the building contained only functional displays. The main issue with this approach was the sensitivity surrounding removing a display owner's working display in order to replace a non-functional one in another location. Our solution to this issue involved an application for a grant in order to purchase a new set of displays. Thus, in June 2011, a set of seven new displays arrived. Although this was not a long term solution, it enabled us to carry on with our research.

4.4.2.2 Midspan Failures

The midspans, as shown in Figure 9, provide power as well as data to the SBCs. In January 2011, two displays experienced connection errors, and it was found that one of the midspans had failed. This required coordinating a visit to the machine room by seeking permission from the University's systems services department. By this point a number of displays had experienced VGA chip issues, thus the two displays which had connection issues were simply re-wired to another midspan, which had unused ports. It should be pointed out that issues that occur within the machine room are more time-consuming as they require an appointment with authorized personnel from the University's systems team.

4.4.2.3 Server Downtime

In April 2010, the windows server that hosted the ASP.NET version of the Hermes2 application (as discussed in section 4.2.2) failed due to a hardware fault. Thus, the displays were re-configured to run the JAVA-based version of the Hermes2 application until the windows server was replaced by the manufacturer. There were also unanticipated issues with the Uninterruptible Power Supply (or UPS), which serves as a messaging system which tells the server to shut down in case there is an issue with power. These issues require trips to the machine room with the aid of a systems administrator to gain access to the cabling.

4.4.2.4 SBC BIOS Issues

A switch within the display enclosure can reset the BIOS settings, which tries to boot using the hard drive. However, the SBCs have been configured to use LAN as its primary boot device. On certain occasions, the displays booted with the BIOS reset and an error that required keyboard input to continue. This meant that the floorboards had to be pulled out in order to manually connect a keyboard to the SBC (through a PS2 port) and reconfigure the

BIOS settings. Figure 14 (left) shows the view of the SBC (with the enclosure unscrewed) underneath the floorboard.

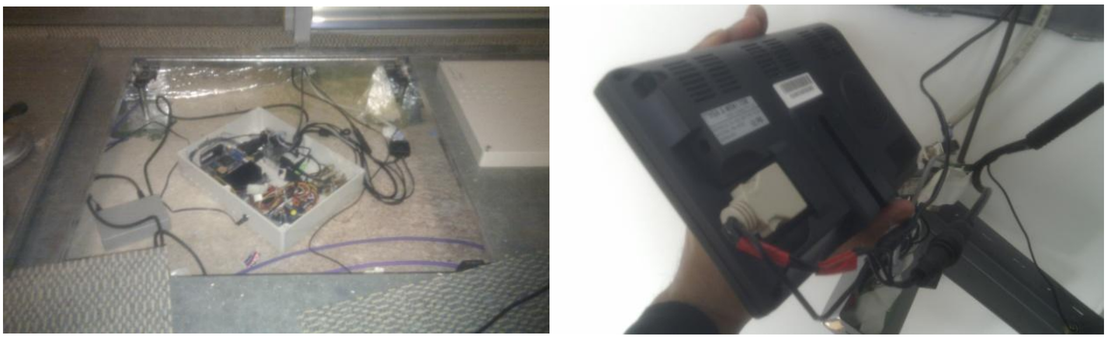


Figure 14 - (left) View of the SBC with the encasing off under the floorboards, (right) inside the Hermes2 display enclosure

4.4.3 Virtualization of Hermes2

The Hermes2 central server machine was removed from the machine room in November 2011 due to a security breach. The server rebooted about 131 days before the date of removal, because the server became unresponsive. On reboot, an installed squid proxy server was re-enabled. This was previously disabled due to security vulnerability (i.e. access to internet was possible from outside the network). This led to the machine being compromised and used for various reasons (some traffic information was stored on log files), for instance downloading large amounts of data (PDFs) from the IEEE website (e.g. research catalogues). This caused IEEE to temporarily block access to Lancaster University, thus impacting the research community. The Information Systems Services at Lancaster University traced this and blocked all external access to the machine. ISS also wanted the machine to be removed.

To resolve the issue, the procedure undertaken was as follows. On the 2nd November 2011, the server was removed from the machine room. A meeting was organized for the 9th November to discuss how the server will be set up with appropriate security and knowledge of all running services. A key issue that led to the incident was the lack of knowledge of all running services on the server. This was caused because the server had been taken over by a number of researchers, who had installed services that were not properly documented. This caused a gap in knowledge and furthermore, led to the issues with the squid server.

To comply with the University's incentive of virtualization of servers, it was decided that the Hermes2 server would be virtualized. A backup of the files had been stored in a terabyte external hard drive. The virtualization was a time-consuming procedure as it required an application process for a specific amount of server space and features. Furthermore, the server essentially had to be re-configured from scratch, which was a challenging task. As the configuration of the system involved the private backbone network of the Hermes2 displays (as shown in Figure 9), a number of meetings were required in order to solve the ways in which the VM would connect to the private network. Once the set-up of the virtual machine had been successful, we undertook the procedure of installing required services and configurations. The entire process was logged and the details can be found in Appendix A.2.

4.5 Chapter Summary

This chapter has described the various components of the Hermes2 deployment, as well as the development process and design rationales of prototype navigation system components (i.e. navigation application, route presentations and client devices). The functionality of the navigation system was also discussed. This was followed by a review of the responsibilities and challenges experienced in relation to managing the Hermes2 deployment as part of our research.

The next chapter describes formative user evaluations that aimed to investigate the feasibility of the prototype Hermes2 navigation system, as well as user motivations, interaction preferences and requirements for using a combination of map-based and three-dimensional route presentations.

Chapter 5

Initial Investigations of the Prototype Navigation System

The prototype Hermes2 navigation system, which has been described in the previous chapter, was developed in order to address the user study objectives presented in section 3.2 of chapter two. This chapter describes the procedures, results and analysis of two user studies. The first study was a preliminary study carried out in August 2008 as part of a Master's project (Taher, 2008) and prior to the research undertaken in this thesis. Findings from this study were encouraging in motivating the first research question described in the Introduction (section 1.2), and repeated as follows.

1) **In what ways do users prefer to interact with an indoor navigation system that comprises of personal mobile phones, an existing situated display deployment (i.e. Hermes2) and a set of 2D and 3D route presentations in an unfamiliar building environment? What interaction and contextual design implications can be extrapolated from the user preferences?**

The preliminary study led to a follow-on study carried out in January 2009, which was part of the research of this thesis. This follow-on study expanded on and addressed limitations faced in the preliminary study, namely the lack of mobile phone use by study participants. In this chapter, both user studies are described, analyzed and discussed. Our investigations focus on: user attitudes towards viewing a combination of two and three-dimensional route presentations (i.e. map and 3D routes), the contextual factors and preconceptions that influence user interactions with the navigation system components, and initial insights towards the use of personal mobile phones.

5.1 Preliminary Study: Investigating User Interaction with Route Presentations and Mobile Phones

The preliminary user study was carried out in August 2008 with eight participants in the Infolab21 building after an initial prototype of the Hermes2 navigation system had been developed as part of a Master's project. We were interested in exploring user motivations, attitudes, and interaction preferences towards the use of the prototype in a natural (albeit with certain constraints, e.g. asking participants to carry out tasks) setting. The study was also conducted in order to assess the feasibility of the navigation system, and whether such a system would be useful for participants in other locations.

5.1.1 Experimental Set-up

The design and development of the prototype navigation system has been discussed in the previous chapter, therefore an overview of technologies used is provided here. The prototype included the following components during the user study: (1) A touch screen kiosk style display, (2) digital 2D maps, (3) 3D route visualizations, and (4) personal mobile phones. The kiosk display was connected to a laptop, which ran the navigation application, and was placed next to the building entrance. The kiosk display enabled study participants to view directions using the navigation application graphical user interface (GUI) to their destination location (using a map and/or 3D route) as well as the ability to download (via Bluetooth) the route presentations to their personal mobile phone. This study used the initial Java-based version of the navigation application (as shown in Figure 15).

The navigation application utilized a Bluetooth based approach in order to enable users to download route presentations. An external Java library known as Bluecove[9] was used. Once users click a "Download" button the navigation application searches for nearby Bluetooth devices and lists them on the GUI. The user is then able to select their device on a list (through the Bluetooth friendly name configured on their mobile phone). The files are then transferred to the mobile phone by using OBEX object push. During the study, the map files were transferred as JPG images and the 3D route visualizations as 3GP.

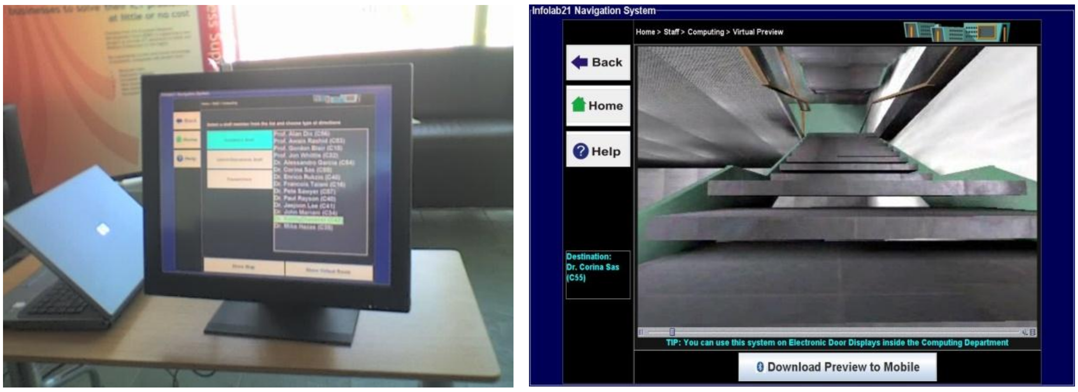


Figure 15 - (left) the study set-up showing the Kiosk display, (right) the 3D route viewed on the navigation application GUI.

5.1.2 Study Approach

The study involved eight participants (4 male, 4 female). A key study objective was to approximate a natural (i.e. ecologically valid) setting, by exposing participants to the prototype system in its intended place of use and by recruiting participants who had no prior knowledge of the building layout. Participants were recruited by sending e-mail invites to Lancaster University students, who were part of mutual clubs and societies. We aimed to recruit participants that represented the target users of the system, that is, users with varying levels of technological expertise and an equal male to female ratio. Once the

[9] http://bluecove.org/ (accessed 17th March 2013).

potential participants had accepted the invite, they were sent an information document (Taher, 2008), which outlined the aims of the study and information regarding privacy of their data. During the study, each participant was initially greeted next to the building entrance and given a task (using a task booklet) to find directions to a given lecturer's office within the building, and asked to physically walk to their destination. An example of a route is illustrated in Figure 16. We adapted a non-obtrusive approach, such that participants were able to choose the route presentation of their preference and whether or not to download the route presentation(s) to their personal mobile phone (a mobile phone was not supplied to participants). It must be noted that a familiarization phase was not included (such a phase would involve users becoming familiar with the navigation application GUI and locating a trial destination). Participants were not provided with any additional assistance nor were they timed. Although our approach aimed to study users in a natural setting, the ecological validity was limited in that participants were asked to carry out tasks, rather than observed in the wild.

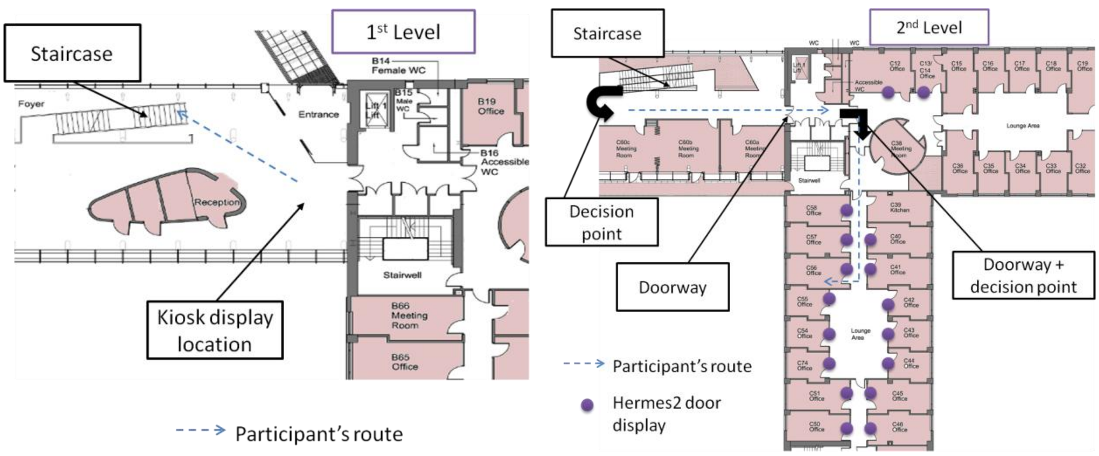


Figure 16 - (left) the starting location of the study, (right) illustration of the participant's route, which involved walking up the stairs, turning points, and doorways.

The duration of the study with each participant varied between 30 to 45 minutes. Throughout the study, think-aloud was encouraged with participants in order to aid our understanding of their thought processes. Observations of behaviours were made whilst participants were walking to their destination. After participants located their destination, a semi-structured interview was carried out in order to discuss their experiences. A questionnaire was then provided in order to gather demographic data, as well as ratings (using a Likert scale) for the usefulness of the navigation system. Throughout the study, observations and important comments that were made by participants were noted down using pen and paper.

5.1.2.1 Procedure

An overview of the first user study procedure is as follows:

- Each participant was greeted next to building entrance and accompanied to the location of the kiosk-display (i.e. study set-up starting location).
- Participants were asked to read the information document (if they had not done so) and to sign a consent form.
- They were provided with a task booklet with a scenario and instructed to think out loud whilst carrying out tasks throughout the study. If they had not spoken for a specific duration (i.e. three minutes) they were subtly reminded to think out loud.
- Participants were observed as they located a given building occupant (e.g. staff member) on the kiosk display and, if they have chosen to, downloaded the route presentation(s) to their mobile phone. Once they had viewed the route presentations on the kiosk display, they were asked to physically walk to the destination location in their own time (i.e. participants were not scored on factors such as time and route efficiency).

- Participants were observed by following them until they successfully located their destination. They were not interrupted or provided with any assistance in finding their location.
- After participants had located their destination, they were accompanied back to the start location to have a discussion (i.e. semi-structured interview) about their experiences. Finally, they were provided with a questionnaire.

5.1.3 Key Findings

The study provided insights on the importance of combining two and three-dimensional route presentations in navigation systems and the factors that affected interactions with the prototype system.

5.1.3.1 Two and Three-dimensional Route Presentations

It was evident that presenting a combination of two and three-dimensional route presentations (i.e. maps and 3D routes) in an indoor navigation system was an important feature which addresses perceptions of what users typically find useful (i.e. to view their route in perspective and/or gain an overall understanding of the environment). For instance, some users may be good map readers and actively seek to use maps, whereas others might prefer to view their route in perspective (i.e. through a 3D route) rather than translating more abstract map representations. Two participants (2/8) commented on the benefits of viewing both route presentations:

"The advantage of the map is that you can see everything but the preview helps you to see what you need to see"

"It's good to see the overall layout as well as have an idea of where you are going".

5.1.3.2 Preconceptions

As the study participants did not undergo a familiarization phase, they were viewing the route presentations for the first time. It was clear that their preferences towards choosing route presentations were affected by preconceptions that were in turn shaped by past experiences and the novelty factor. For example, participants who had chosen to only view the map (4/8) expected that the 3D route might be unhelpful and difficult to understand. Two participants (2/8) who chose to view only the 3D route felt that maps were generally confusing from past usage, and that the 3D element provoked more curiosity and interest. During the semi-structured interview, participants were shown both route presentations and it was found that non-3D route users actually would have found the 3D route useful for receiving directions to their destination.

5.1.3.3 Context

The observations revealed ways in which contextual factors affected their navigation task of walking to their destination. For instance, the think-aloud protocol revealed that participants counted the number of doors whilst viewing the route presentations in order to help guide them whilst walking. One participant used the photocopier as a landmark in order to make a turn. Another participant was unsure whether a public foyer area was public or private, as it required going through a door (which was numbered at the top, giving the impression it was a “room number”). Four participants (4/8) felt that the route to their destination was straightforward and it was therefore unnecessary to download route presentations to their mobile phone.

5.1.3.4 General Attitudes

During the study, (7/8) participants were successful in finding their destination locations. One participant located the incorrect office due to recall issues and could not remember the office number of their destination location. The Likert scale ratings shown in Figure 17 demonstrate positive user attitudes towards the system. Participants also felt that a similar system would be useful in other on-campus departments:

"I think it would be extremely useful as departments tend to be full of windy corridors"

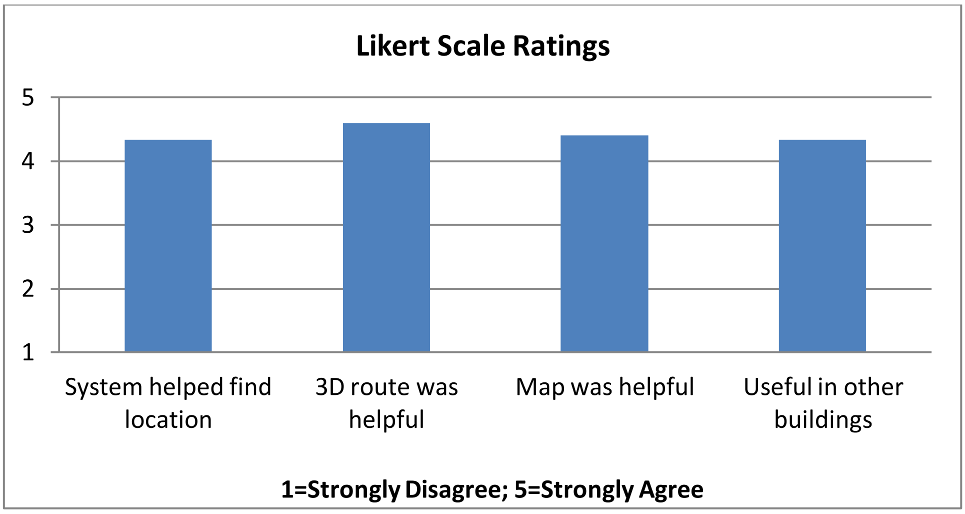


Figure 17 - Likert Scale ratings towards the overall use of the prototype navigation system.

5.1.3.5 Summary

The insights received from the study were encouraging and revealed some initial and important factors that need to be addressed in the development of indoor navigation systems, for example, the benefits of providing survey and route-based spatial representations. The study also provided an understanding into the factors that motivate users to select specific route presentations. Whilst this finding by itself is not overwhelming, it certainly adds to the understanding of users and their motives. Initial insights towards contextual factors were also evident, such as the usefulness of landmarks, and also the issues that can be caused by the structure of the environment. A doorway to a foyer area, for instance, caused confusion for one participant as to whether it was an office, and therefore, private area. In terms of mobile phone use, four participants who attempted to download the route presentations were either unsuccessful due to technical (Bluetooth) issues or made minimal use of their mobile phone en-route. The next follow-on user study aimed to address the limited insights gained towards mobile phone use.

5.2 Study One: Follow-on Study Exploring User Interaction with Route Presentations and Mobile Phones

The follow-on study was undertaken as part of the research of this thesis and involved six participants (3 male, 3 female). The key objective of this study was to expand on the previous study and explore mobile phone use. The set-up of the prototype navigation system and the approach were repeated from the first study (as described in sections 5.2.1 and 5.2.2), but with the following changes:

- To investigate user attitudes towards the use of personal mobile phone, study participants were asked to download route presentations to a mobile phone to aid them whilst walking to their destination location. A Nokia N80 mobile phone was supplied with Bluetooth capability. This was done to avoid technical issues that were faced in the previous study.
- Minor tweaks were made to the navigation application GUI, such as re-organizing the placement of the buttons that enable users to view the map and 3D route visualizations. In the first study it was found that two participants did not notice the button for viewing 3D routes.

Study participants were recruited in a similar manner to the preliminary study (i.e. Lancaster University society members were sent e-mail invites). Similarly, we aimed to represent the target system users by recruiting participants with varying levels of technical expertise and an even male to female ratio. Before the study, participants who had accepted the study invite were sent an information document (see Appendix B.1). They were greeted next to the entrance of the Infolab21 building and were given a task sheet (see Appendix B.2) that asked them to get directions to a staff member's location and also walk to their location (a similar route to Figure 16 was used). This was followed by a semi-structured interview and a questionnaire (see Appendix B.2) to collect demographic data and also collect general user attitudes towards the prototype system's components through Likert scales. Observations and important comments made by participants were noted using pen and paper. The procedure of this study was mainly repeated from the previous study, as described in section 5.1.2.1 of this chapter, with the exception that participants were encouraged to download route presentations to the supplied Nokia N80 mobile phone (i.e. before carrying out their first task of looking for a staff member using the kiosk display). In addition, the duration of the study with each participant was similar to the previous study (i.e. between 30 to 45 minutes).

5.2.1 Key Findings

The findings from the follow-on study re-confirmed the key findings and observations made in the previous study and also provided insights towards the usefulness of mobile phones for navigation.

5.2.1.1 Comparison of Repeated Findings

The findings in this study generally replicated those from the previous study. In this study, all participants noticed both the 3D route and map option when using the navigation application GUI to find directions. The importance of presenting a combination of route presentations was re-confirmed. For instance, four participants (4/6) who chose to view both the map and 3D route stated that while it was beneficial to view an overview of the environment the 3D route provided more information about their particular route. One participant commented:

"They were both very useful and if I had both, and one confused me, I could use the other"

The motivations for choosing to view route presentations were also similar to the previous study (i.e. participants had similar preconceptions). One participant who chose to view the map stated that they were already familiar with maps and expected that the 3D route would be complicated. Three of four participants who viewed both route presentations stated that they either were initially hesitant to select the 3D route as they were unsure of what to expect, or had a preconception of what it might look like. For instance one participant expected a "cube-like representation showing the route". One participant who chose to view only the 3D route suggested that it made more sense to be able to visualize the route.

This study demonstrated that participants utilized landmarks, such as doorways, to help guide them to their destination. General attitudes towards the usefulness of the prototype system were similar to the previous study, as shown by the Likert scale in Figure 18. We also asked general questions in the questionnaire about the usefulness of the route presentations and whether the amount of detail was sufficient. Figure 18 shows that participants were generally happy with the design of the map and the 3D route visualizations. One participant commented that it would be beneficial to use bolder lines to distinguish between corridors and rooms. Two participants (2/8) stated that the playback speed of the 3D route could be slightly slower.

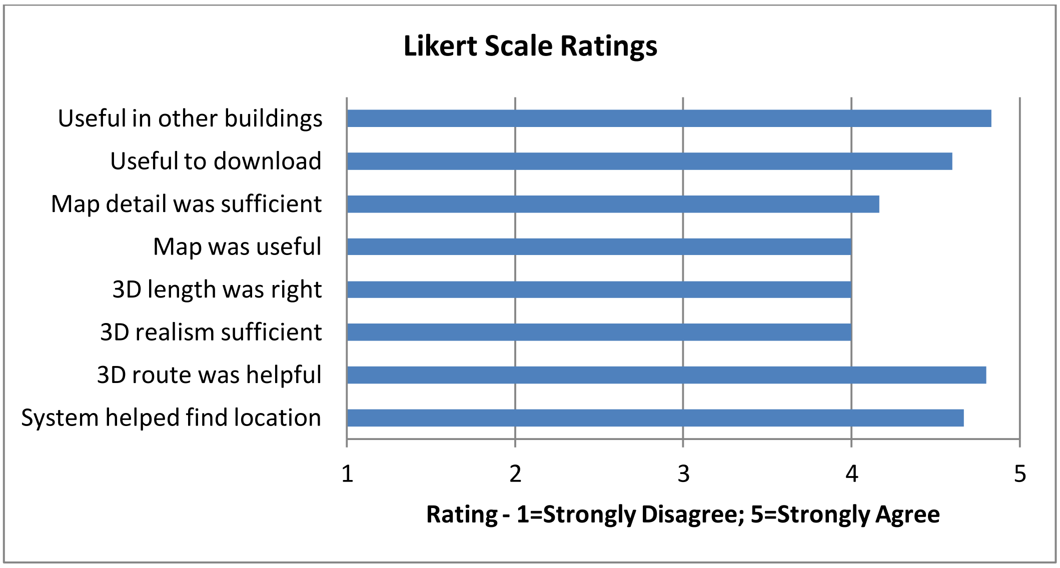


Figure 18 - Likert Scale ratings of the overall usage of the prototype navigation system.

5.2.1.2 Mobile Phone Use

In terms of mobile phone use, all participants commented that by being able to download route presentations, it increased their sense of security whilst finding their way. For instance, three participants stated:

"I felt more secure by having the 3D route on my phone"

"The phone allowed me to refer back to the map"

"I would have the map on phone to feel secure about not getting lost"

While walking to the destination, all participants had a tendency to continuously glance between their mobile phone and their surroundings in order to match information on the map or 3D route to the physical environment. In contrast to the preliminary study, observations revealed that participants were more confident whilst they were walking to their destination (e.g. walking at a faster pace with less pauses).

5.3 Discussion

The two user studies described in this chapter provided early insights into user interaction and context-related aspects of the prototype Hermes2 navigation system. It was found that an important requirement for indoor navigation systems is to provide a combination of two and three-dimensional route presentations (e.g. a map and 3D route visualizations). The studies showed that some participants (6/14, from both studies) used a structured approach to get directions to their destination by initially viewing the overall layout of their environment (e.g. using a map) and then viewing their route in perspective to gain familiarity (e.g. using a 3D route). The availability of both route presentations can also address scenarios where users might choose to download the map on their mobile phone, but later find (whilst en-route) that the 3D route would have been more useful. This assertion is supported by finding that study participants who only viewed the map (i.e. 3/14 participants from both studies) at the beginning of their task, later stated that they would have preferred to view the 3D route (i.e. during the semi-structured interview).

Another key finding concerned user motivations for choosing route presentations. As participants in both studies did not undergo a familiarization phase, they were viewing the route presentations for the first time when they were asked to find directions to their destination. An interesting factor that affected participants' motivations to view the map rather than 3D route visualizations was the pre-conceived complexity of the 3D element. While it can be argued maps are simply more familiar and therefore comfortable to use, past experiences with 3D representations of the environment can also affect user motivations. The demographic data from the questionnaires revealed that none of the users had previously used 3D route presentations for the purposes of navigation. The exposure to these environments has mainly been in the context of video games (e.g. Quake) and virtual tours (e.g. campus tours, estate agents housing websites), which aren't specifically tailored for the purposes of navigation. It would therefore be interesting to observe the way that user perceptions might change over time given the advances in 3D modelling technologies and more frequent usage of 3D representations for navigation support (e.g. Google Street view).

In addition, the general attitudes towards the prototype system were positive and motivated further investigations which are discussed in the next chapters. Participants from both studies described in this chapter were keen on describing other locations where such a system would be useful, thus highlighting the need for digital indoor navigation systems.

The two user studies described in this chapter revealed that choosing a route presentation is a complex activity. If we consider the subject-community-object model, which is described in activity theory (Nardi, 1996), choosing to view a route presentation (mediated by the navigation application GUI) involves a number of interrelated factors such as past experiences, novelty, and familiarity (see Figure 19). Therefore, designers must be aware that these factors can shape and influence the ways in which users choose to view route presentations in indoor navigation systems. Finally, the designer must also be responsible for adequately designing the navigation application GUI such that users are able to make an informed decision in relation to selecting a route presentation. For instance, in the first study two participants overlooked the option for the 3D route visualization due to the button placement on the GUI.

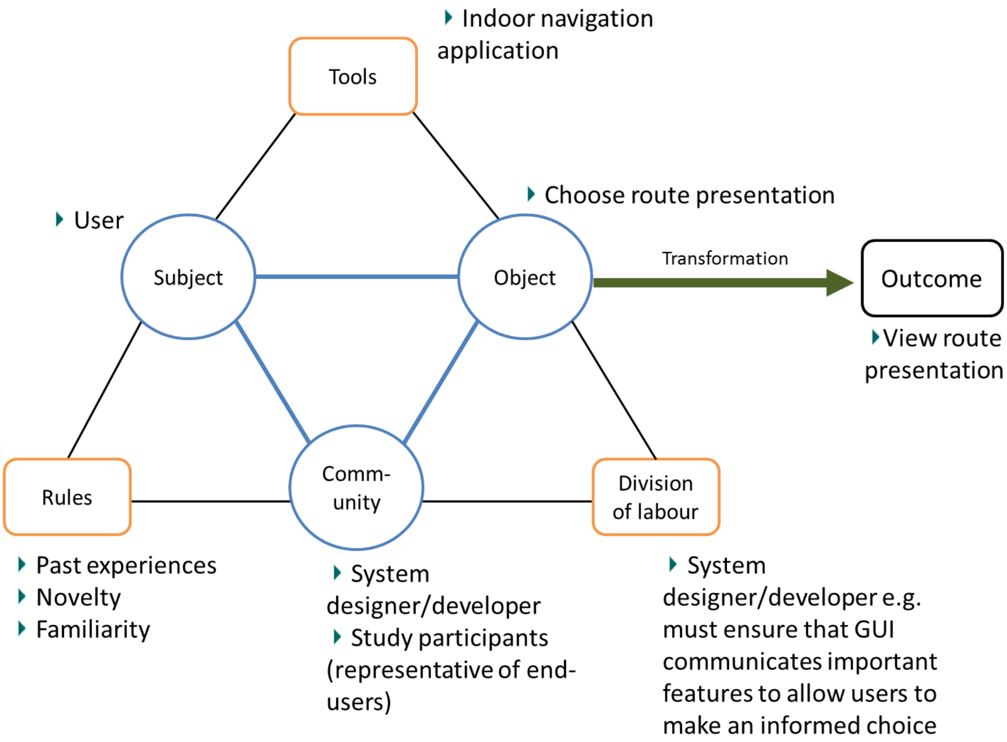


Figure 19 - Activity model for viewing a route presentation on the prototype navigation application GUI.

5.3.1 Limitations

The approach towards approximating a natural setting was largely successful in revealing various important insights. However, the ecological validity was affected by the nature of the study (e.g. asking participants to carry out tasks) rather than observing them in the wild. For instance, the studies explore a more recreational form of navigation (i.e. participants are not under any pressure). We anticipate that user interactions and preferences would be different if users faced time-constraints and/or other situational factors. The preliminary study revealed the limitations of a less-controlled approach, which led to a lack of understanding towards mobile phone use. Rogers et al (2011) describe that one of the issues with natural settings is that "it is difficult to anticipate what is going to happen", and that "participants may not try out the full range of functions provided by the device". The follow-on study provided more insights towards mobile phone use, however, like the insights towards route presentations, these were mainly general and were not based on specific interaction preferences and requirements. Therefore, the next user studies described in the forthcoming chapters have sought to address these limitations.

5.4 Chapter Summary

This chapter has described two formative user evaluations which have provided a number of initial and important insights towards the development of useful and usable indoor navigation systems. We have highlighted the importance of combining spatial representations as well as developed an understanding of the motivations that affect user preferences for viewing route presentations. As the integration of the Hermes2 deployment was during the stages of implementation, the next step in our research was to investigate the feasibility of adapting the deployment for the purposes of assisting visitor navigation.

The next chapter describes three studies which aimed to investigate display owner attitudes as well as user attitudes, preferences and requirements towards the integration of the Hermes2 deployment in our prototype navigation system.

Chapter 6

Feasibility of the Hermes2 Deployment for Assisting Visitor Navigation

A number of early insights towards the use of the prototype Hermes2 navigation system were described in the previous chapter, in particular, user preferences and motivations towards selecting route presentations and the general use of the prototype system. The next stage of our research was to establish the feasibility of adapting the Hermes2 deployment (i.e. the Hermes2 situated displays and the messaging application) into our navigation system. This involved conducting three evaluations: a questionnaire-based study to investigate requirements of its primary users (i.e. display owners), a user study that aimed to explore and gather insights from system users, and a short user study that focused predominantly on situated display interaction. These studies allowed us to address the first two research questions described in chapter one, as repeated below:

1) **In what ways do users prefer to interact with an indoor navigation system that comprises of personal mobile phones, an existing situated display deployment (i.e. Hermes2) and a set of 2D and 3D route presentations in an unfamiliar building environment? What interaction and contextual design implications can be extrapolated from the user preferences?**
2) **To what extent can the physical and software components of the Hermes2 display deployment be adapted to assist visitor navigation and mitigate the requirement for a new digital infrastructure?**

6.1 Study Two: Hermes2 Display Owner Attitudes

A questionnaire study was carried out in March 2009 to explore whether Hermes2 display owners were prepared to provide information which is already provided on the messaging application (such as status messages, e.g. "Gone for coffee") on the prototype Hermes2 navigation system GUI, as well as allowing their door display to share content (e.g. a graphical arrow) that would assist visitors in trying to find their way to a staff member's office. We observed the messages that were set on the door displays on a single day in March 2009 and found that several messages appeared to be relevant to assisting navigation (i.e. the first three shown below) whereas others are clearly not:

"[Display owner name]'s Office Hours: Mon – Wed 08:00 – 16:30; Thu & Fri 08:00 – 16:00"

"Gone for coffee"

"Back soon"

"Check it, before you wreck it"

In addition, we were interested whether the display owners would be willing to allow photograph-based icons to be used on the navigation application GUI (to help visitors identify them), as well as if they are generally happy for visitors to view the route to their office (e.g. using the Kiosk display in the reception area). Furthermore, we explored the possibility of whether visitor navigation can be assisted by enabling communication between the visitor and the display owner, for instance, through SMS text messages on a mobile phone. We envisage a scenario where a visitor utilizes the kiosk display and finds that the display owner is away for an hour, and then decides to compose a message using an on-screen keyboard, which is then sent to the display owner's mobile phone.

6.1.1 Study Approach

Questionnaires (see Appendix C.1 for an example of a completed questionnaire) were provided to twelve participants who were Hermes2 display owners in the Infolab21 building. The aim was to include display owners that were representative of the user types (e.g. lecturers, administrative staff, researchers, and PhD students), as well as a mix of male and female participants. These included six administrative staff, four researchers and two lecturers (8 female, 4 male) with an average age of 32.4 years. The questionnaire included general questions towards the frequency of their display usage, as well as Likert scale based questions that aimed to measure owner attitudes (e.g. whether they were willing to share their display messages for supporting visitor navigation on other displays such as the kiosk display). Paper-based questionnaires were printed out, and the occupants of several offices with working displays were approached. They were informed about the research aim and the anonymity of their data. As this was a questionnaire-based study, a consent form was not required. Participants were given approximately two weeks to complete the questionnaires.

6.1.2 Key Findings

The Likert scale ratings shown in Figure 20 from the questionnaire revealed that display owners were generally comfortable with allowing visitors to view directions to their office (i.e. through 3D route visualizations or maps), sharing the messages set on their displays, and allowing their photograph to be used on the Hermes2 navigation application GUI. One participant commented:

"Practical [to allow visitors to view my temporary message on the graphical user interface] in case I go home, ideally I could use my mobile phone/computer to set that message, for example if I decide in the morning to work from home"

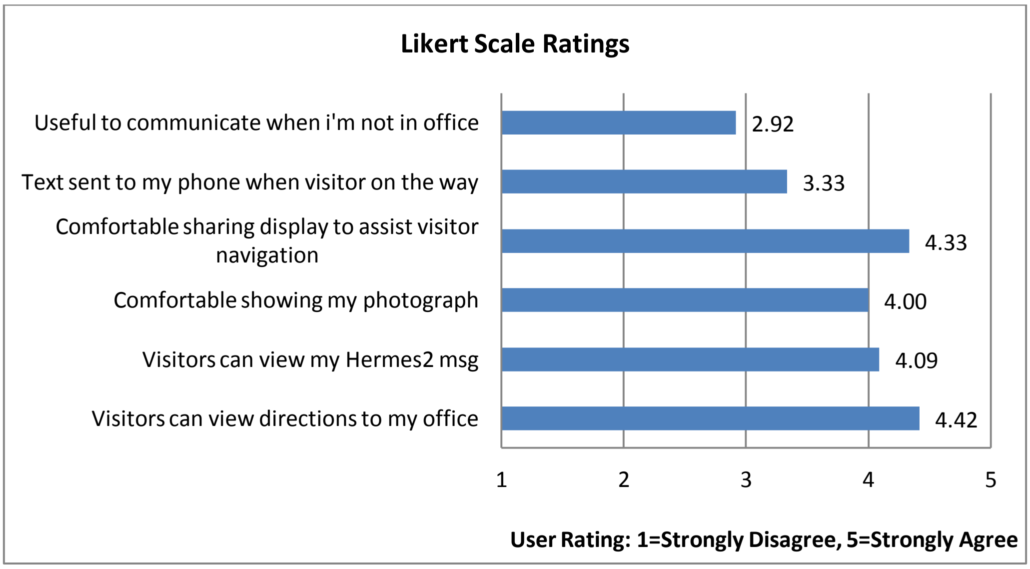


Figure 20 - Likert scale ratings displaying display owner attitudes towards integrating the Hermes2 deployment.

Display owners were also willing to share their displays to assist visitor navigation. These findings echo the initial investigations into display owner attitudes carried out by Kray et al (2006), where it was found that display owners responded with either "Agree" or "Strongly Agree" (mean = 4.67) on the Likert scale for the question "generally happy for my Hermes display to be used to support the navigation system". In terms of communicating with visitors, our questionnaire revealed that display owners were less enthusiastic. For instance, one participant who disagreed with this feature commented:

"This would suggest that I would use my private phone for the use with the University. It would also imply I might use it to contact students, thus incurring costs".

6.1.2.1 Implications of Display Usage

One of the main contributors towards the success of using display owner messages for assisting visitor navigation is the frequency of usage. For example, if display owners are rarely using the displays, then the messages will not be useful as they would not reflect current activity. Our questionnaire also included questions regarding display usage. Figure 21 below shows that there is a spread across those who never (generally) set a message on their displays and those who set them monthly, weekly, and daily.

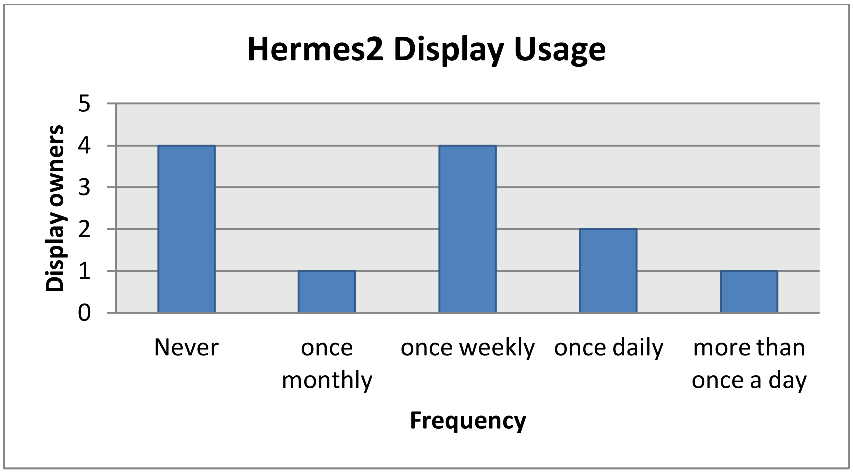
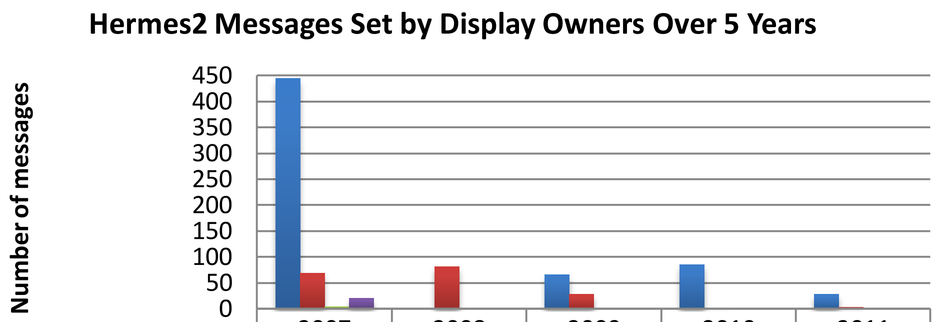


Figure 21 - Frequency of display usage by 12 display owners.

In order to examine the frequency of use over time a PHP script was developed that enabled queries to the MySQL database logs on the Hermes2 server with date ranges to calculate the number of messages that have been set by display owners. Figure 22 below shows the usage of the Hermes2 displays and the number of messages that have been set over time. It is evident that over time, the number of messages that were set decreased. The reasons behind this were due to technical issues, which have been described in section 4.4.2 of chapter four, thus affecting the trust that display owners had towards the system.



	2007	2008	2009	2010	2011
Temporary messages	445	0	66	85	28
Temporary images	69	81	28	1	3
Default messages	4	0	0	0	0
Default images	20	0	0	0	0

Figure 22 - Messages set on the displays by display owners over a 5 year period.

6.1.3 Summary

In summary, the questionnaires provided encouraging feedback towards motivating the integration of the Hermes2 displays and its messaging application for the purposes of supporting visitor navigation. Display owner requirements were also investigated, which included showing navigation-related content as transparent overlays in order to prevent original content from being obscured (Kray et al, 2006). Furthermore, it was clear that owners require the ability to stipulate whether specific features can essentially be switched on or off (e.g. enabling and disabling mobile phone messaging between visitors and display owners). This was found through varied responses in the questionnaires, where for instance, one display owner was happy sharing their photograph whilst another was not. It was therefore apparent that an ideal solution would be to allow customizable options on the Hermes2 web-portal, which would allow display owners to enable/disable features based on their preference.

6.2 Study Three: Integration of the Hermes2 Deployment

To explore the usefulness of the Hermes2 deployment (i.e. the situated displays along the corridors and the messaging application that it supports), a user study was carried out in March 2009 using the prototype Hermes2 navigation system with an initial integration of the Hermes2 deployment functionality. The next section describes the set-up in more detail.

6.2.1 Experimental Set-up

The set-up of the prototype Hermes2 navigation system consisted of: (1) A touch screen kiosk style display, (2) digital 2D maps, (3) 3D route visualizations, (4) a Nokia N80 mobile phone (Figure 23), and (5) Hermes2 situated displays. The Kiosk display was connected to a laptop which ran the Java-based Hermes2 navigation application.

Figure 23 - (left) Java-version of the navigation application GUI with photographic representation of staff members and their display messages underneath (right) Nokia N80 mobile phone.

Modifications to the navigation application consisted of the following. We added functionality that queried the Hermes2 server in order to access display owner details such as the message set on their display. These were then displayed on the application GUI. The staff members were represented through photographic icons (e.g. see Figure 23) based on consent from the questionnaires in the previous study. Furthermore, the GUI enabled users to request graphical directional arrows to be requested en-route (i.e. by adding a button that allows this functionality). These were designed to be shown on the displays that preceded the user's destination location. Due to limitations with our implementation the functionality of the arrows in this study utilized a Wizard-of-Oz approach, such that the arrows on the displays that directed them to their destination were generated and shown prior to the study (i.e. they were left on the displays throughout the session with each participant).

6.2.2 Study Approach

The study involved ten participants (5 male, 5 female). The approach and procedure from the studies described in the previous chapter were repeated (section 5.2.2). For instance, participants were invited from the University clubs and societies, and they were sent an information document prior to the study (see Appendix D.1) once they had confirmed participation. The sampling technique utilized was also similar to the previous two studies, that is, participants were required to have little to no exposure of the building, have varying levels of technological expertise, and were mixed gender. They were initially greeted next to the building entrance, provided a task to locate a staff member, asked to choose a route presentation to receive directions to their destination, and required walk to their destination with the help of the Nokia N80 mobile phone (i.e. by downloading the route presentation of their choice). The route participants' undertook is illustrated in Figure 24. These tasks were communicated using a task sheet (see Appendix D.2). This was followed by a semi-structured interview and a questionnaire (Appendix D.2) to collect demographic data and user attitudes towards the use of the system using Likert scale questions. Observations and important comments made by participants were noted using pen and paper. The duration of the study with each participant was approximately 45 minutes.

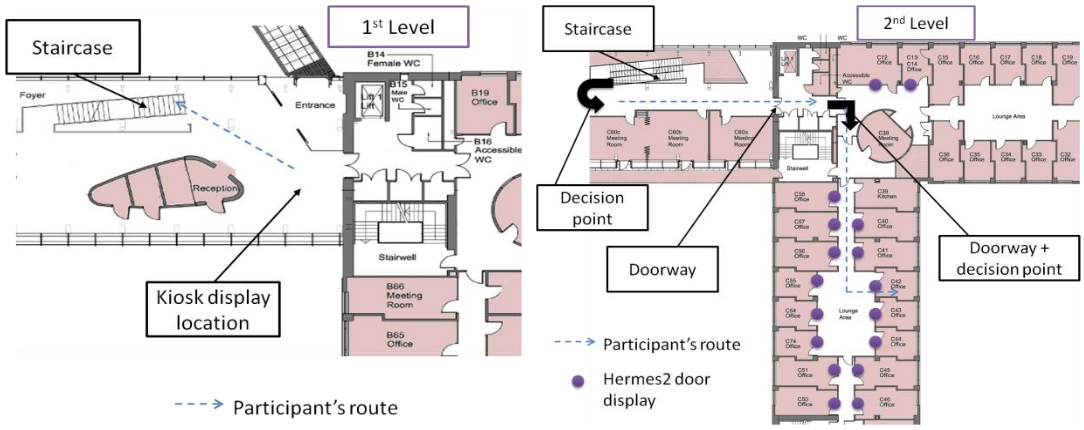


Figure 24 - (left) starting point of the participants' route, (right) the next building level showing the decision points, doorways and the route.

6.2.2.1 Procedure

The procedure of the third user study was as follows:

- Each participant was greeted next to building entrance and accompanied to the location of the kiosk-display (i.e. study set-up starting location).
- Participants were asked to read the information document (if they had not done so) and to sign a consent form.
- They were provided with a task booklet with a scenario and instructed to think out loud whilst carrying out tasks throughout the study. If they had not spoken for a specific duration (i.e. three minutes) they were subtly reminded to think out loud.
- Participants were observed as they located a given building occupant (e.g. staff member) on the kiosk display and downloaded the route presentation(s) to the Nokia N80 mobile phone. Participants were then asked to physically walk to the destination location and to use the mobile phone to help find their way.
- Participants were observed by following them until they successfully located their destination. They were not interrupted or provided with any assistance in finding their location.

- After participants had located their destination, they were accompanied back to the start location to have a discussion (i.e. semi-structured interview) about their experiences. Finally, they were provided with a questionnaire.

6.2.3 Key Findings

The study re-confirmed a number of findings in the previous studies (i.e. the preliminary study and the first user study), and it also provided encouraging insights towards the use of the Hermes2 deployment.

6.2.3.1 Repeated Findings

The repeated findings in this study echo both the preliminary and first user study, which have been described in the previous chapter. For instance, the importance of combining route presentations was re-iterated. Three participants (3/10) chose to view both the 3D route and the map. One participant stated that the map was important for receiving orientation information, whereas the 3D route enabled visualization of their route. As part of future use, eight participants stated that they would use both the map and 3D route visualizations to get directions.

Preferences for choosing route presentations were similarly (to the previous studies) linked to expectations, novelty factor, and familiarity. One participant chose to only view the 3D route as he expected the map just be "one of those classic maps", and that the 3D element seemed more interesting. Another participant who only viewed the map stated that the map was simply more familiar.

Eight participants (8/10) felt that the mobile phone was useful and it enabled them to feel more confident along their route. For instance, one participant stated:

“It is faster to have this [3D route] on the phone because you don’t have to look around and ask people”

In contrast, one participant had significant difficulties following the 3D route visualization on the phone. Another participant stated that they preferred to view environmental signage rather than follow a map-based presentation on a mobile phone. In this case, the participant only viewed and downloaded the map, but later found that the 3D route would have been more useful (i.e. when the participant was shown the 3D route during the semi-structured interview).

6.2.3.2 Hermes2 Integration

Insights towards the usefulness of the Hermes2 situated displays were limited. This was caused by the lack of clarity provided by the navigation application’s GUI and (7/10) participants were unsure of what to expect from the button which allowed users to request graphical directional arrows. Furthermore, the study procedure did not provide encouragement to use this feature, but rather it was hoped that participants would notice it. Thus, insights were only received towards the utility of the display owner messages and the possibilities of extending the navigation application’s functionality to communicate with display owners. All participants agreed that viewing a display owner’s message on the navigation application GUI was a very useful feature as it informed them about the location of the display owner (or staff member).

“The message under staff members was helpful because I previously had to wait for lecturers outside their office”.

Participants were asked if they would find it useful to send a message to a lecturer displayed on the kiosk GUI in cases where their message indicated that they were unavailable (e.g. “Back tomorrow”). This could be achieved, for example, through utilizing the navigation application to send a text based message using an on-screen keyboard. Nine participants (9/10) were keen on this feature. It was clear that an e-mail based messaging system seemed more appropriate than, for instance, messages sent to a display owner’s mobile phone. However, four (4/10) participants mentioned that in an emergency situation (e.g. for coursework submissions) an SMS based messaging system would be beneficial.

“...I would feel comfortable sending an e-mail than text as I feel that a text would be more intrusive”.

“If in need of emergency [sending a mobile text message] may prompt the staff member to hurry or they could send you a message to tell you where to find help elsewhere”.

6.2.4 Summary

This study re-confirmed the usefulness of using personal mobile phones for navigation support and presenting a combination of two and three-dimensional route presentations. We also found that participant’s preconceptions of route presentations were similar to the ones found in the previous studies. The insights towards the use of the Hermes2 deployment were limited due to methodological issues as well as the limitations of the navigation application GUI. We did, however, find that participants’ attitudes towards features such as display owner messages and the ability to contact display owners were positive (i.e. the messages can help visitors determine whether a staff member might actually be within the building).

6.3 Study Four: Re-examining Hermes2 Display Interaction

Due to the limitations of the previous study in terms of exploring the use of Hermes2 displays, we decided to re-asses our methods of investigating the potential of integrating the Hermes2 deployment into the navigation system. For instance, we investigated whether the arrows need to be shown on the side of the corridor where the user's destination is located, or alternatively, on both sides of the corridor. We carried out a short, and informal, user study involving in-depth discussions to receive some early insights towards the feasibility and the interaction preferences for viewing route presentations on the Hermes2 situated displays. This study was carried out in July 2009 with three participants.

6.3.1 Experimental Set-up

In this study, we were in the early stages of developing the ASP.NET version of the Hermes2 messaging application, and also the ASP.NET version of the Hermes2 navigation application. This decision of re-implementation was made in order facilitate the process of rapid prototyping, and also to allow a more cross-platform approach. The components used in this study consisted of the touch-screen kiosk style display, and the Hermes2 digital displays. This preliminary version of the .NET navigation application GUI enabled users to select a staff member (through photographic icons) and select a graphical directional arrow to be shown on the displays along their route.

6.3.2 Study Approach

This user study involved three participants (1 female, 2 male), who were members of a mutual society at Lancaster University. They were invited to participate in the study through e-mail. As the participant count was low, the study was kept informal. Correspondence was made via informal emails with colleagues from other departments which informed them about the study and the privacy of collected data. Participants were greeted next to the building entrance and asked to carry out a task that involved locating a display owner and choosing an arrow to view along their route. Participants were then asked to walk to their location. In order to provoke ideas towards the types of interactions they might prefer with the displays, we asked participants to touch each arrow on the displays along their route in order to disable them. Following this, a semi-structured interview was carried out. The time spent with each participant was recorded using audio. The study lasted approximately 30 minutes for each participant.

6.3.2.1 Procedure

The procedure undertaken in the fourth user study was as follows:

- Participants were greeted next to the building entrance and were accompanied to the study set-up location. They were provided with the participant information document to read and then asked to sign a consent form.
- A task sheet was given to participants, which had step-by-step instructions to look for a given building occupant and select an arrow (from various colour styles) to view on the Hermes2 displays along their route.
- Participants were then asked to physically locate their destination location by following the arrow they had chosen, on the Hermes2 displays whilst thinking out loud. They were also asked to tap each display along their route to toggle off the semi-transparent arrow's visibility (and therefore return to the display owner's graphical user interface).
- Once they had located their destination, participants were accompanied back to the set-up location to engage in a semi-structured interview about their experiences and preferences.

6.3.3 Key Findings

The feedback we received from participants can be categorized as preferences for the placement, route presentations, and interaction styles with the situated displays.

6.3.3.1 Display Placement

The study revealed that all three users had different preferences regarding the placement of the Hermes2 displays for receiving navigation assistance along their route. For instance, one participant would prefer to see the displays along the floor. Another participant stated that they would prefer to see a situated display on the top (close to the ceiling). The third participant was comfortable viewing the displays to the side. We also asked participants whether it was appropriate to view the graphical arrows on the displays on a particular side of the corridor (e.g. on the side of the corridor where the user's destination office is located) and two participants confirmed that they would normally assume their destination office would be located on the side of the corridor which is showing the graphical arrow.

"Normally I would assume if the arrow is on the right or if it's on the left the [destination] office would be on that side, because you wouldn't have an arrow on the right and suddenly you have an arrow saying this way and it's opposite the actual office"

6.3.3.2 Route Presentations on the Displays

We were interested in the types of information that participants would find helpful to supplement the graphical arrows. Participants suggested information such as the amount of time left and the number of doors that required passing till they reach their destination.

"If [the display] tells me that I need to walk five minutes towards this place, if I pass five minutes or if I'm near five minutes I would know…"

Participants also stated that they would find it useful if they were able to view route presentations such as a digital 2D map or 3D route visualization on the Hermes2 displays. For instance, one participant stated that they would prefer to view a 3D route and the remaining two would prefer to view a map.

“[a map on the display] that says you are here and your destination is here would be very useful and then when you get to the next [display], touch it, you are now here and your destination is here…”

6.3.3.3 Display Interaction

All three users confirmed that they would prefer the arrows to appear automatically as they approached the Hermes2 displays as well as disappear after they have passed by. It was stated that it would be far more effective and less time consuming than having to touch each arrow in order to disable it as they walked by. Two participants had concerns regarding office occupants when interacting with the displays.

“Say the person is inside at work and you just come here and touch your arrow on the display, they might think, what are you doing?”

Furthermore, two participants stated that would prefer to interact with the displays only if they were disoriented or unsure of their current location along their route.

6.3.4 Summary

This user study provided encouraging and early feedback from the user’s point of view (i.e. the visitors who will be using the displays to navigate) towards display interaction. The previous study (study 3) mainly revealed insights towards the use of the messaging application. This study further motivated the integration of the Hermes2 situated displays for the purposes of navigation support.

6.4 Discussion

The questionnaire-based study revealed encouraging feedback from the display owners towards sharing the Hermes2 displays to support visitor navigation, given that specific requirements were met. For instance, it was preferred if the original content on the displays (i.e. the messaging application) was not completely obscured, which led to the requirement for showing navigation related content (e.g. a graphical directional arrow) with a semi-transparent overlay.

In study three, it was made clear by participants that the messages left by display owners (by using the Hermes2 messaging application) would be particularly useful in situations where they are able to determine that a staff member is away before walking to their office. This of course, depends on the regular usage of the messaging application by display owners. It is also necessary to include timestamps for each message in order to ensure that a message saying “back in 5 minutes” was not set over a month ago. The data in Figure 22 show that the frequency of setting messages by display owners have declined over a period of time, mainly due to technical issues experienced with the Hermes2 deployment (as discussed in chapter four), which have impacted display owners’ trust towards the system’s reliability. However, the Hermes2 system was not designed to be a commercial solution, but rather a test-bed for carrying out research projects. It was nevertheless found that such a messaging application can provide useful benefits for a navigation system. At the same time, it is also important for designers to be aware of the consequences that technical failures can have on user trust.

The Hermes2 messaging application inspired investigations into the potential of enabling visitors, who are seeking navigation assistance, to communicate with the display owners using the kiosk display at the reception. From the questionnaire and user studies it was clear that sending mobile messages, although they can be more reliable than sending e-mails (e.g. in study three, one participant stated that a lecturer rarely responded to emails), they are also more personal. While visitors such as university students find the idea of being able to unfailingly contact a staff member more attractive, it is not entirely reciprocated by staff members, who might feel that student-faculty communication becomes too personal. Thus, a useful feature would involve providing a facility on the navigation application GUI to be able to send messages to display owner's e-mail accounts. At the same time, it is imperative that display owners are provided with the flexibility of enabling or disabling this feature (e.g. through changing settings on their web-portal).

The fourth study aimed to address the lack of insights received for situated display interaction in study three. This study was informal as we were in the early stages of re-implementing the navigation application GUI. At the same time, we also wanted to ensure that the displays would be useful for visitor navigation. Feedback from participants was positive and we also received some early and encouraging insights towards interaction requirements in terms of display placement, route presentations, and interaction styles. These findings inspired ideas that were investigated and expanded upon in the user studies described in the next chapter (e.g. display placement, the feeling of discomfort using the displays, etc.).

6.4.1 Implications for Integrating the Hermes2 Deployment

A shared display deployment such as Hermes2 must meet the requirements of its users, especially its primary users (i.e. the display owners). The primary users must also permit the appropriate functionality in order to allow visitors to set messages for the display owners, as well as enable visitors to receive navigation assistance using the display content. It is likely that visitor navigation will be affected, and therefore mediated, by the rules set by the primary users (display owners) of the Hermes2 deployment. For example, if certain display owners choose to disable features that enable users to view their display messages on the kiosk display, or if they decide to un-share their display for assisting visitor navigation, then the efficiency of visitor navigation will be affected. Therefore, the successful integration of technology such as the Hermes2 deployment must be mediated by a joint effort from system designers and display owners. The system designers need to meet user requirements and the display owners need to facilitate the process of allowing their displays to support visitor navigation. Figure 25 below represents the activity model showing the interrelated factors that surround the integration of the Hermes2 deployment for supporting navigation.

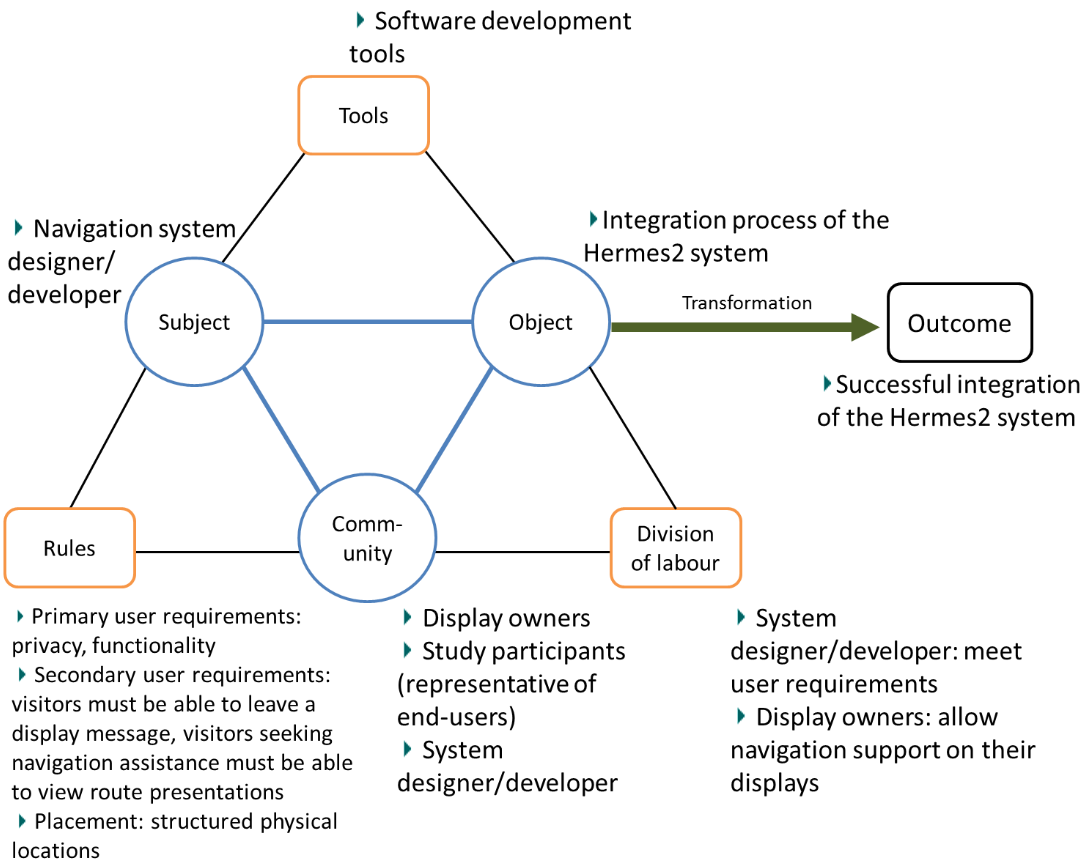


Figure 25 - Activity model depicting the interrelated components that must be considered when adapting existing technologies.

6.4.2 Limitations

The studies in this chapter provided general insights into the feasibility of adapting the Hermes2 deployment into our prototype navigation system. Although this was an important step, studies three and four, for instance, did not enable us to receive deeper insights into the ways in which users prefer to interact with the various components of the prototype system. These limitations were mainly caused by the approach utilized in these studies, where we aimed to approximate a natural setting. Whilst this approach was successful in uncovering insights of "why" participants chose route presentations, it was necessary to introduce more control into the tasks that participants are asked to carry out (i.e. in the next user studies). Furthermore, a more rigorous approach to evaluation methods is required. The questions in the semi-structured interviews need to be more specific towards the types of interactions preferred and required, for example, with mobile phones and route presentations.

6.5 Chapter Summary

This chapter described three user evaluations which revealed a number of insights towards the attitudes of the primary users (i.e. the display owners) as well as the secondary users (i.e. the visitors seeking navigation support) of the Hermes2 system. The interviews with the display owners revealed positive attitudes towards sharing the displays for the purposes of visitor navigation given that specific requirements were met (e.g. customizability of features and using a transparent overlay to show navigation related content). Studies three and four demonstrated that users were interested towards integrating the functionality of the Hermes2 messaging application, as well as the displays, in supporting navigation.

The next chapter expands on the studies described in this chapter and the previous chapter by addressing the limitations and also exploring interactional and contextual aspects surrounding the use of the prototype Hermes2 navigation system.

Chapter 7

Exploring Interaction and Context

The previous chapter has motivated the integration of the Hermes2 deployment in the prototype navigation system. We identified that the primary users (i.e. display owners) were keen on display sharing for navigation, given that specific requirements were met. Furthermore, studies three and four provided early insights that both the messaging application and the situated displays were useful components for assisting navigation. In this chapter, two user studies are described (i.e. studies five and six). Study five aimed to address limitations faced in previous studies and utilized a more controlled approach to the studies in order to explore preferences and requirements for mobile phone use, route presentations, and situated display use. Study six, further explored the interplay between mobile devices and situated displays with the intention of uncovering insights towards location-awareness and contextual factors that surround the use of the navigation system. The studies in this chapter addressed the research questions described below:

1) **In what ways do users prefer to interact with an indoor navigation system that comprises of personal mobile phones, an existing situated display deployment (i.e. Hermes2) and a set of 2D and 3D route presentations in an unfamiliar building environment? What interaction and contextual design implications can be extrapolated from the user preferences?**

2) **To what extent can the physical and software components of the Hermes2 display deployment be adapted to assist visitor navigation and mitigate the requirement for a new digital infrastructure?**

7.1 Study Five: Interaction Preferences and Requirements

The main objective of this study was to investigate user interaction preferences and requirements for indoor navigation support using a combination of mobile and situated displays along with route presentations such as digital 2D maps, 3D route visualizations and graphical directional arrows. The study was carried out in August 2010.

7.1.1 Experimental Set-up

The prototype Hermes2 navigation system consisted of the following components: (1) A touch-screen kiosk style display (2) the Hermes2 situated displays, (3) A HTC Desire mobile phone, and (4) route presentations such as 2D digital maps, 3D route visualizations and graphical directional arrows. In this study, the ASP.NET version of the navigation application was used. The GUI enabled users to view and select from a list of staff members (represented by photographs) and receive directions to their office by means of a digital 2D map and 3D route visualization. In this study, we experimented with using a QR code (or barcode) approach to enable participants to take away route presentations. The GUI displayed a barcode (e.g. see Figure 26) generated using a barcode generator on the web[10], which can be scanned by an off-the-shelf open source barcode scanner application[11] on the mobile phone.

[10] http://qrcode.kaywa.com/ (last accessed 20th March 2013).
[11] http://code.google.com/p/zxing/ (last accessed 20th March 2013).

An HTC Desire mobile phone was supplied to participants during the study to avoid technical issues. The barcode essentially directs users to a separate web-page (also developed with ASP.NET) with a simplified GUI that enables users to view the map and route visualization to the selected destination. For instance, participants in the user study were able to view the map and 3D route visualization to their destination on the phone after having viewed this content on the kiosk display GUI.

Figure 26 - (left) Kiosk display set-up, (right) HTC Desire mobile phone scanning a QR code on the navigation application GUI.

7.1.1.1 Route Presentations

The GUI was also designed to enable users to request graphical directional arrows on fixed displays. This was carried out through a look-up table which was set up as a MySQL table on the Hermes2 server. Therefore, during the study, when participants requested graphical arrows, the navigation application would use the destination location in order to retrieve the appropriate set of displays that need to show the arrow.

In terms of route presentations, the map used in this study was adapted from an architectural floor plan, rather than using a CAD-drawn map. Modifications included annotations such as a You-Are-Here marker, a dotted line marking the user's route and a map key (for objects such as doorways, stairs and the user's route). To account for multiple floors, the maps were presented on the GUI one floor at a time, that is, the subsequent floor is viewed by pressing a "show next step" button. The 3D route visualizations did not undergo any additional modifications.

7.1.2 Study Approach

To assist with the procedure of our study, as well as to inform the set-up of our prototype navigation system, a storyboard was developed (see Appendix E.1). The storyboard helped illustrate the different types of interactions that users might go through whilst using the prototype system. The methodology employed in this formative study was predominantly informed by the past studies (described in the Background section), that is, we observed what appeared useful and what appeared ineffective. The number of participants recruited was generally quite low and we did not receive significant feedback pertaining to the combined use of mobile and fixed displays. Thus, we utilized a more controlled approach in this study such that participants were encouraged to use certain features of the navigation system. This study involved 16 participants (8 male, 8 female) with an average age of 24.31 years (2.66 stdv), and none of whom had previous experience of the building. They were recruited by placing flyers around the University campus. Potential participants were directed (by e-mail) to an online spreadsheet (Google Document-based) in order to coordinate times of participation. The sampling technique remained similar to the studies in the previous two chapters, that is, participants had varying technological expertise. Each participant was provided with a monetary reward upon completion of the study. Prior to the study, they were e-mailed with an information document (see Appendix E.2) in order to provide information about the aims of the study and also regarding privacy of data. The duration of each study was approximately between 30 and 45 minutes.

Figure 27 - Participant walking to their destination using the mobile phone.

Evaluation methods used during the study included think-aloud, observation, semi-structured interviews and questionnaires (see Appendix E.4). A Dictaphone, which was used to record the entire session with each participant, enabled us to capture think aloud data. A video camera was used to record participants whilst they were walking to the lecturer's office, thus enabling us to observe interaction with the mobile phone and the physical environment.

7.1.2.1 Procedure

The procedure for this user study was as follows:

- Participants were greeted at the Infolab21 building entrance and were accompanied to the study set-up location, where they were provided with the participant information document (in case they had not already read it) before they were asked to sign a consent form.
- During the study, participants were given two task sheets (Appendix E.3) with seven different instructions on each sheet. The first set of instructions was designed to allow participants to become familiar with the system.

- As part of the first set of instructions, participants were asked to select a given lecturer on the kiosk display in order to view route presentations. By following the instructions on the task sheet, they viewed map-based directions to the destination office, followed by the 3D route visualization.
- Participants were also asked to become familiar with requesting graphical arrows en-route by carrying out the action on the kiosk display, and by viewing the map and route visualization on the mobile phone (i.e. by scanning a QR code on the kiosk display GUI). The supplied mobile phone was already connected to the internet via 3G and participants were not required to pay for connection costs.
- Participants were then verbally prompted to become familiar with the controls on the mobile phone, such as pausing and playing the 3D route visualization and zooming in and out of the map.
- The task sheet required participants to repeat the previous steps for a different building occupant. However, once participants had scanned the QR code on the kiosk display, they were verbally asked to physically locate (i.e. walk to) the lecturer's office using the supplied mobile phone to help guide them. Furthermore, they were verbally informed about the Hermes2 situated displays showing graphical arrows en-route, provided with the Dictaphone to wear around their neck, and encouraged to think out loud whilst walking to their destination.
- Participants were allowed to choose whether to use the map or visualization (or both) on the mobile phone. The route included two turns, that is, one 180-degree turn at the top of a staircase and one 90-degree turn after two sets of double doors (as shown on Figure 28). The task sheets ensured that all participants were exposed to both the digital 2D maps and the 3D route visualization.

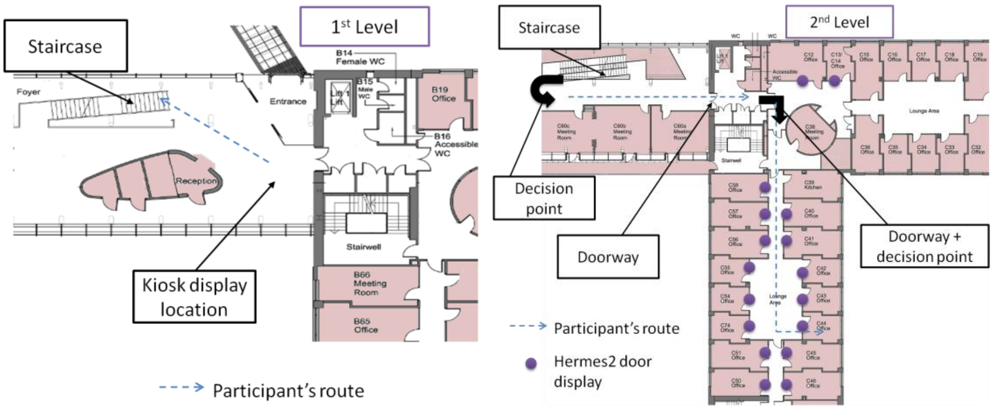


Figure 28 - (left) starting location of the user's route, (right) participants' route on the second level showing decision points and doorways.

- Whilst participants were walking to their destination they were followed at a short distance and recorded with a video camera. They were not offered any assistance or prompted to carry out any further actions until they had reached their destination, at which point they were accompanied back to the study set-up location to engage in a semi-structured interview. This was followed by a questionnaire to gather data such as demographics.

7.1.2.2 Grounded Theory Analysis

The analysis of data adapted a grounded-theory approach such that the general objective was to uncover user preferences and requirements for interacting with the various components of the indoor navigation system, which led to a number of categories that were formed through coding. Firstly, the audio and video recordings for each participant from the user study were initially transcribed into text (i.e. using Microsoft Word) and then coded. This was achieved by using a spreadsheet into which relevant keywords and themes were added (see Appendix E.5) into a table. These keywords were attached with descriptions of observed participant actions as well as quotations. The keywords and themes were motivated by a number of methods. These included observations from the previous user studies described in chapters five and six. The finding that participants found it useful to view a combination of route presentations (preliminary study, study one and three) led to asking participants about their preferences in the ways of switching between the map and 3D route visualization on the mobile phone. The use of landmarks for navigation assistance (preliminary study, study one and three) led to noting the types of landmarks participants found useful en-route to their destination. The preconceptions of the 3D route visualizations and the map in all previous studies led to asking participants about their requirements and interaction preferences. Furthermore, as participants overlooked the displays in study three, the reasons for this were explored in the fifth study, for instance, by looking for occurrences where participants stated they were fixated on the mobile phone. The significance of the themes was also based on the quantity of participants that contributed to them, as well as the relevance to the research questions.

During the user study, observations during each session with participants led to follow-up questions in the semi-structured interview (e.g. if it was observed that a participant had not noticed a situated display, they were asked why this may have occurred). Common themes were also noted down during the interviews (using pen and paper) and then later marked-up (or coded) in the text-based transcripts. Furthermore, recurring themes were marked-up (i.e. highlighted) during the transcription process (i.e. whilst writing up the text from the recordings). The main categories therefore consisted of user preferences and requirements for: (1) interaction with the route presentations, (2) interaction with the situated displays (3) interaction with the mobile phone, and (4) interaction with the combined set of navigation system components. After the categories were formed, an informal meeting with a colleague (who was carrying out research in the HCI domain) was organized in order to discuss the findings and to ensure that potential themes had not been overlooked. The next few sections describe the findings related to the aforementioned categories in more detail.

7.1.3 Key Findings

The findings from our study can be categorized into interaction preferences for route presentations, situated displays, mobile phones and combined use of components.

7.1.3.1 Interaction Preferences for Route Presentations

Fourteen of the 16 participants chose to view only the 3D route visualization and (2/16) participants viewed only the map on the mobile phone. Seven participants (7/16) commented that the visualization was easier to use. We anticipated that the digital 2D maps would cause limitations as they were modifications of the building's architectural floor plans; however, only (2/16) participants (one of whom generally disliked using maps) commented that the map was difficult to understand when viewed on the kiosk display. There was no direct correlation between the type of route presentation viewed on the mobile phone and general attitudes toward using traditional maps. One of the two participants who used the digital 2D map to physically locate the destination office commented that he already had a general idea of the route after viewing the visualization on the kiosk display and, hence, decided to use the map. The other participant commented that the map was preferable whilst walking as it would keep up with her pace.

Design Considerations for Maps

We were interested in receiving feedback on the type of information and interactions that users would like when using the digital 2D map to navigate. One key issue is matching map orientation on the phone to the user's orientation. Two participants (2/16) who used the map to locate their destination manually rotated the map and also commented that they would prefer this form of rotation rather than any automation. This finding is also supported by the study carried out by Seager and Fraser (2007). In contrast, five participants (5/16) who did not use the map to walk to the destination commented that it might be useful to have automatic map rotation on the mobile phone. However, this suggestion was speculative as these five participants did not experience walking with the map. Thus, automatic map rotation was regarded simply as a design consideration which users will be able to enable or disable. Furthermore, (4/16) participants suggested that a location-aware You-Are-Here marker on the map would be useful whilst walking to their destination (on the phone).

As the maps were based on modified architectural floor plans, unrelated annotations were removed using CAD software. However, (2/15) participants felt that there was too much detail. One participant would have preferred more color on the map.

Design Considerations for 3D Route Visualizations

A key topic of discussion mentioned by participants during the semi-structured interviews concerned the playback speed of the 3D route visualization video clip. All 16 study participants were happy with the playback speed on the kiosk display; however (11/16) participants would prefer the video clip on the mobile phone to be either slowed down (i.e. adjusted to walking speed) or to maintain appropriate control of its speed. Suggestions of playback controls include the use of a slide bar, plus/minus buttons and automatic adjustment to walking speed.

Four participants (4/16) who were walking to their destination location using the 3D route visualization on the mobile phone faced difficulty in matching the environment in the visualization to the physical environment, especially in terms of: (a) appearance of objects (or lack of objects) and (b) the scale of the environment. Two participants (2/16) for instance, were unsure if they were in the correct room as the furniture in the physical environment was not represented in the 3D route visualization. Three participants (3/16) also stated that they would switch to the digital 2D map if the environment in the 3D route visualization did not correspond to the physical environment. Thus, a constraint of the 3D route visualization as continuous media (rather than interactive) is that users are unable to view the environment outside of that route.

The study showed that landmarks in the 3D route visualization (when viewed on the kiosk display) played a significant role. Nine out of sixteen participants used landmarks for reassurance along their route, which were: (a) the kitchen, (b) the appearance of the doors, (c) a circular shaped room and (d) office door numbers.

"I remembered the glass door and I remembered the sort of curvy wall thing, and when I found those I thought oh I am going the right way 'cos I remembered, I saw these".

7.1.3.2 Interaction Preferences for Situated Displays

In addition to mobile phone use, we investigated whether it would be useful to supplement user navigation by showing graphical directional arrows on fixed displays along a user's route. Nine out of sixteen participants noticed the displays. Eight participants (8/16) commented that by viewing the graphical arrows on the displays, they felt reinforced and reassured and also that this type of assistance would save time.

"It helps reinforce the fact that you were going the right way so if you were using a system like this and if the phone technology started to play up then you've got something sign wise telling you that you were going the right way".

Two participants (2/16) in particular, were unsure of their location at a certain position along their route, however after noticing the graphical arrows on the Hermes2 displays they felt reassured and carried on to successfully locate their destination. Seven out of sixteen (7/16) participants however, did not notice the displays, mainly due to being fixated on the route presentations displayed on the mobile phone. The study confirmed that the Hermes2 displays were useful in circumstances where participants were unsure of their location. This caused participants to observe the surrounding environment, thus noticing the graphical arrows. Furthermore, the displays were useful as an additional form of information (to a mobile phone) which provided participants with reassurance and reinforcement along their route.

The configuration of the Hermes2 displays was such that participants, during the study, would come across them approximately half-way in their route. Eight participants stated that they would prefer to view the graphical arrows on the displays at the beginning of their route or at decision points (e.g. at the first turning point).

7.1.3.3 Interaction Preferences for Personal Mobile Phones

By observing participants as they walked to their destination location it was apparent that all participants paused (between approximately three and fifteen seconds) at the two decision (i.e. turning) points in their route (see figure 8). The think aloud data showed that all participants had an understanding of the directions to the destination location after viewing route presentations on the kiosk display and furthermore, (12/16) participants confirmed that they had a rough idea of their route before setting off. However, the think aloud and observation revealed that participants were more reliant on following instructions on the mobile phone. Participants would pause frequently to interact with the mobile phone to, for instance, pause and play the 3D route visualization or work out the subsequent navigation step. The (12/16) participants also confirmed that they “wanted to make sure” that they were walking in the right direction.

"'Cos I didn't want to get lost, I just wanted to make sure that I was going the right way. I didn't want to be wandering around…"

Our study also showed that participants were predominantly fixated on the mobile phone whilst viewing route presentations, or they used both the mobile phone and Hermes2 displays (which showed graphical directional arrows). Thus, participants did not use any traditional signage (e.g. on the wall signs) to find their way to the destination.

7.1.3.4 Interaction Preferences for a Combination of Components

In terms of viewing both digital 2D maps and 3D route visualizations on a mobile phone, (11/16) participants confirmed that it was essential to be able to easily switch between the two presentations. During the user study, participants were able to switch between the two by pressing the back button on the phone and selecting another form of content. However, participants suggested different methods of content switching. These include: (a) the ability to simultaneously access the digital 2D map and 3D route visualization, (b) starting the 3D route visualization for a specific point on the map (e.g. by tapping), (c) pressing a small graphical button at a corner to switch to another form of content (e.g. from 3D to map) and (d) by having both the map and 3D route visualization open in window format. Three (3/16) participants stated that they would switch to the digital 2D map view if the environment in the 3D route visualization did not correspond to the physical environment.

"I guess if I took a wrong turn, 'cos if the 3D only takes you on the route you're meant to go and you're not on that route then it's not so useful. So if I was standing outside a room and it wasn't on the 3D route, then I wouldn't know how to get back on it. Then the map would be helpful".

The graphical directional arrows on the Hermes2 displays were unnoticed by (7/16) participants, despite being informed by the GUI of their appearance and also being instructed to expect the displays en-route. By observing the seven participants it was clear that they were fixated on the route presentations displayed on the phone.

7.1.4 Summary

The fifth user study enabled us to develop the insights towards the preferences and requirements for personal mobile phones, situated displays, and a combination of route presentations. The key findings are summarized as follows:

- It was evident that the need for customization and control was higher when users interacted with a mobile phone in comparison to a situated display system such as the kiosk display. For instance, it was clear that a control mechanism was required for the playback speed of the 3D route visualization when viewed on a mobile phone (as opposed to the kiosk display).
- In our study we found that using a mobile phone to view navigation content en-route is beneficial in mitigating limitations posed by structured display configurations (i.e. areas without displays that would show navigation content such as graphical arrows).
- Our study showed that digital signage shown on fixed display systems (such as Hermes2) provides reassurance in different circumstances when navigating. These include cases where the displays may be used as (a) an additional source of navigation content to a mobile phone, (b) when facing difficulty using a mobile phone, and (c) as an opportunistic information source.
- It is essential to consider the accuracy of navigation information provided on a mobile device as our study showed that (12/16) participants had a tendency to rely on the

device rather than their sense of direction (especially as 12 users stated that they already had a rough idea of the route before walking to their destination).

7.2 Study Six: Interaction, Context, and Location-Awareness

The intention of this sixth and final study was to investigate an approach to location-awareness, which addressed issues such as providing assistance for multiple users (e.g. in a busy environment). We were also interested in further investigating the interplay between mobile phones and situated displays, which was not adequately explored in study five. Furthermore, we investigated the contextual aspects that surround the use of the prototype navigation system.

7.2.1 Experimental Set-up

The navigation system set-up was mainly repeated from the previous (fifth) user study, however with the following amendments. We utilized a Nokia N9 mobile phone with an NFC tag reader/writer and low-cost passive NFC tags were attached to the kiosk display and the Hermes2 situated displays. Several modifications to the functionality of the navigation application were also made.

The navigation application was designed to provide two different services through two separate graphical user interfaces: the *Person Locator* service and the *Location Checker* service. The Person Locator GUI was designed to be used on the kiosk and the situated door displays. The GUI (Figure 29) enables users to: (1) search for a building occupant (e.g. staff member), who are represented using photograph based icons, (2) receive directions to their destination by viewing a map and a first-person 3D route visualization, and, (3) register with the system by touching their NFC-enabled phone on a passive NFC tag attached to the kiosk display. If this GUI on the door displays is not used for 30 seconds, the display returns to its original messaging application.

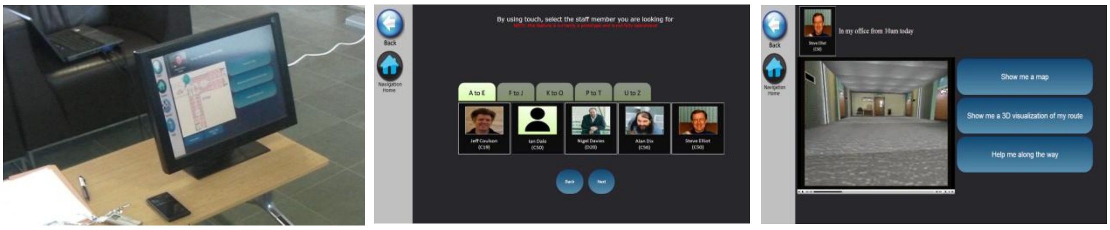


Figure 29 - (left) Kiosk display set-up near the building entrance, (middle) navigation application Person Locator GUI, (right) 3D route visualization shown on the GUI.

The Location Checker GUI (as shown in (Figure 30) was designed to be used if a user has registered their mobile phone with the system (e.g. after receiving directions to their destination). When a user touches their mobile phone on a display's NFC tag, the display then shows: (1) a graphical arrow pointing in the direction of their destination, (2) an updated 2D map showing their current location and destination, and, (3) an updated 3D route from their current location to their destination. If a user touches their phone on the display of their destination office, a confirmation of arrival message is shown. If the Location Checker GUI is unused for 30 seconds, the display returns to the messaging application. The interaction involving the phone and situated displays was designed to be lightweight, such that users can stop, tap the display with their phone to view an arrow, and walk away. Alternatively, users can spend longer by also viewing the map and the 3D route on the display.

Figure 30 - (left) arrow shown on the situated display on the Location Checker GUI, (middle) map view on the GUI, (right) 3D route visualization on the GUI.

The mobile phone used during the study was a Nokia N9 integrated with an NFC reader/writer. The first objective of using the phone was to enable study participants to "take away" the map and 3D route visualization of their route after using the Person Locator GUI. These were viewed on the phone as media files (PNG map and FLV 3D route). During the study these were already stored on the phone to avoid any downloading issues. Thus, the maps and 3D routes did not update to their current location once they touched the NFC tags on the displays. We were interested in the feasibility of the interaction technique before further extending the functionality of the navigation system. The phone was also designed to be used as a low-effort input device to view the Location Checker GUI on the situated displays, that is, to effectively inform the system that "I am here at this office". Alternatively, this could have been achieved by physically interacting with a display (e.g. by entering a unique code). However, the mobile phone enables users to skip this step by functioning as a unique identifier. In order to read NFC tag data and post it to the server, an open-source application known as NFC Interactor[12] ran in the background. The application originally printed out NFC tag information, but it was modified to also post data to the server.

7.2.1.1 Location-Aware Support

Each NFC tag attached to the situated displays and kiosk display consists of a unique symbolic coordinate (e.g. http://www.urladdress/DOORDISPLAY_C45). Users must first register with the system by using the navigation application's Person Locator GUI to select their destination. Once users touch the "Help me along the way" button, they can touch their mobile phone on the NFC tag attached to a display. The NFC Interactor application running on the phone then sends the coordinate information stored on the display's tag to the server (using the building's Wi-Fi connection), along with a unique ID specific to that

[12] http://www.nfcinteractor.com/ (last accessed 18th March 2013).

mobile phone and the user's destination location coordinates. This information is then stored in a MySQL database. The registration process enables the system to be scalable for multi-user support. This process is shown in Figure 31 below.

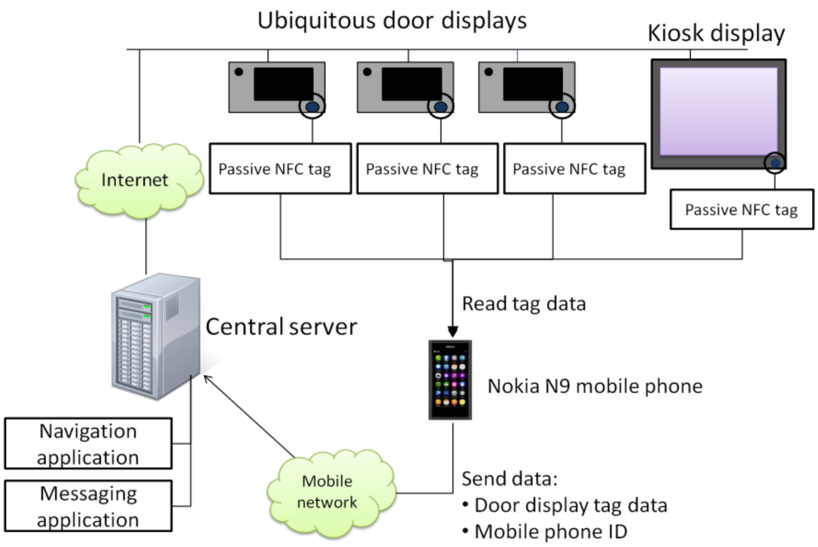


Figure 31 - The communication process of the NFC location-aware approach.

To receive localized en-route support, users are required to use their mobile phone to touch a situated display's NFC tag. The posted display coordinates are compared with the user's stored destination on the central server. The relevant graphical arrow, 3D route, and map (or the confirmation of arrival message), are then shown on the Location Checker GUI on the situated display. Thus, the navigation application is unaware of the users' location until they interact with a situated display using their mobile phone.

7.2.2 Study Approach

Similar to study five, we developed a storyboard to help inform our study procedure as well as the set-up of our prototype system (see Appendix F.1). The study was carried out in September 2012 and it involved 15 participants (7 female, 8 male) with an average age of 25 years (3.68 stdv). Participants were recruited by asking colleagues to contact people who would be interested in participating in this study (and had no previous exposure to the building). Once sufficient candidates that met the criteria (i.e. varying levels of technological expertise and mixed gender) were found, they were e-mailed and then provided with an information document if they agreed to participate in the study. Participants were asked to think aloud whilst carrying out their tasks. Each study session was recorded with a dictaphone. The walking tasks (i.e. when participants were asked to physically locate a building occupant) were recorded with a digital video camera. Participants were not timed or provided with any extra assistance to find their destination locations. One of the key aims in our study procedure involved ensuring that participants interacted with all combinations of route presentations and displays (which were also counterbalanced to avoid bias).

7.2.2.1 Procedure

The procedure utilized in this study was as follows:

- Each participant was greeted near the Infolab21 building entrance, given a briefing of the study process and asked to sign a consent form (see Appendix F.2).
- Participants were given a questionnaire to collect demographic data, followed by three task sheets with instructions (Appendix F.3). The first task sheet was designed to familiarize participants with the kiosk and mobile phone interactions (e.g. panning and zooming on the phone). The trial procedure was as follows:

  Step 1. Locate a given staff member by viewing a 3D route and map on the kiosk GUI.

  Step 2. Register the Nokia phone by touching the NFC tag on the kiosk.

  Step 3. View both the map and 3D route on the Nokia phone.

- The viewing order of the map and 3D route were counterbalanced with participants in all three tasks.

- The second task sheet firstly repeated the above two steps (for a different staff member). Participants were then asked to walk to the staff member's office (Figure 6) by viewing the map on the Nokia phone (counterbalanced with 3D route) as a navigation aid. Whilst walking, participants were prompted by the experimenter to interact with the first door display en-route to ensure they were noticed. Here they viewed a graphical arrow, and were also asked to view the localized map and 3D route on the displays. They received no further prompts after this and the subsequent use of displays was left to their discretion.

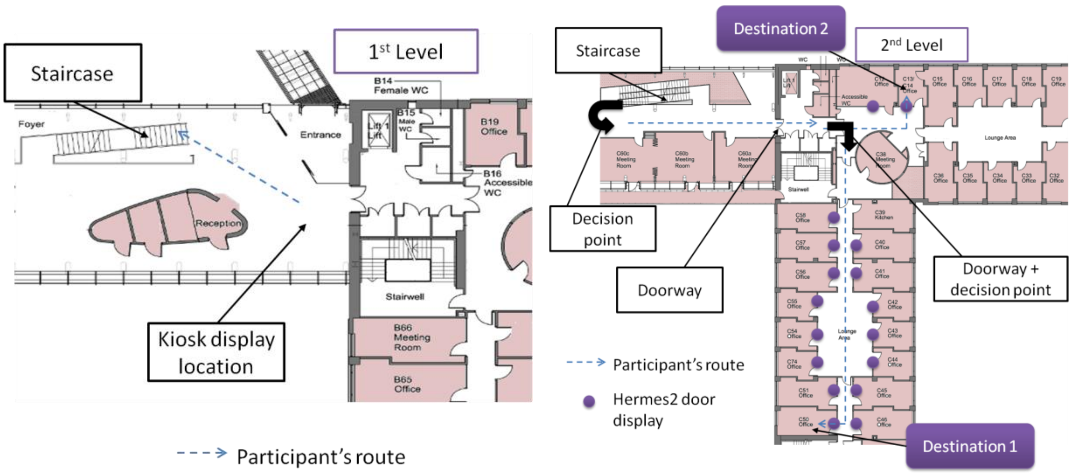


Figure 32 - (left) start location of the participants' task, (right) participant's route to destination 1, and then from destination 1 to destination 2.

- Once participants successfully located their first destination, they were asked to locate another staff member. The first two steps from the previous tasks were repeated. However, this time they used the navigation application on the door display GUI rather than the kiosk. They were then asked to register the Nokia phone and view the 3D route (counterbalanced with map) as a navigation aid whilst walking to their second destination. Participants were not prompted or assisted by the experimenter while they were walking.

- After participants located their second destination, they were accompanied back to the study set-up location where a semi-structured interview was carried out.

It must be noted that whilst participants were walking to their destinations, other than prompting them to interact with the first display en-route, they were given the freedom to interact with any further displays before reaching their destination (to prevent added interruptions to the task). The first prompt was necessary because our previous studies revealed that the displays were typically overlooked, even though participants were informed about the displays.

Figure 33 – Study participant interacting with a situated display using the Nokia N9 mobile phone.

7.2.2.2 Grounded Theory Analysis

Similar to study five, we utilized a grounded-theory approach in order to determine themes and categories (i.e. as described in section 7.1.2.2). This study focused on a combination of the social dynamics surrounding the navigation system components and user preferences for receiving localized navigation support (phone and display interaction with NFC). Audio and video recordings were transcribed into text and then coded with the help of a spreadsheet (see Appendix F.5). Themes and categories of interest were added to the spreadsheet, as well as the relevant observations and participant quotations. Keywords such as privacy, user discomfort (using the displays), the aspects of the navigation system that were regarded as useful, expectations and ease of use (e.g. if using the phone to touch the displays to receive navigation support felt natural) were highlighted in the transcripts. The investigations surrounding the notion of discomfort whilst using the displays, as well as privacy, were motivated by the findings from study four (described in Chapter six), during which two participants stated that they were concerned about the office occupant whilst interacting with their door display. This issue was therefore further investigated in this (sixth) user study. In addition, similar to the approach in study five, any interesting observations, for example, during the walking task (i.e. when participants were physically locating their destination locations) were followed up in the semi-structured interview.

The categories that emerged from the coding process included: (1) the impact of display location and ownership on user interaction, (2) the requirement of privacy for navigation in indoor spaces, (3) ways in which users prefer to interact with a combination of mobile and situated displays, as well as utilizing the NFC based touch interaction to receive localized navigation assistance, (4) the preferences surrounding the need for receiving localized navigation assistance, and (5) ways in which users prefer to interact with the various components of the navigation system. These categories are discussed in more detail in the following subsection.

7.2.3 Key Findings

The results of this study consist of a number of context-related findings, as well as interaction preferences and requirements.

7.2.3.1 Display Location and Ownership

Six out of fifteen (6/15) participants felt uncomfortable using the situated door displays during the study. This was caused by a number of factors expressed during the semi-structured interviews. Firstly, the door displays are located adjacent to office doors on a transparent wall, which means the office occupants were visible. The blinds can be closed (as shown in Figure 1), but this is left to the occupant's preference. It was clear that (6/15) participants perceived that the displays were owned by the office occupants, thus causing uncertainty as to whether they were available for use. Furthermore, the intention behind using the displays was unrelated to communicating with the person inside the office. This caused (6/15) participants to feel intrusive and self-conscious, despite carrying out a quick and lightweight phone/display interaction. One participant was concerned that even if the blinds were shut by the office occupant, it would be embarrassing if they opened the door and found the participant using the display.

"It takes us into the realm of eavesdropping or spying perhaps, or it's just proximally not something you generally do. It's a bit like personal space, for me, the office"

The (6/15) participants who experienced discomfort were asked about how this could be minimized. Suggestions included: (1) placing the displays in more public spaces such as foyers, (2) placing the displays on opaque surfaces so that users cannot see (nor can be seen by) display owners (3) sign-posting the displays to clearly communicate their availability for assisting visitor navigation. Relocating the displays would, however, be ineffective for the messaging application, which is designed to enable communication between users and the display owners. Thus, sign-posting and/or placing additional purpose-built displays (e.g. in decision points – a preference suggested in study five) would be a better solution.

It was also suggested that if other users were seen using the displays for navigation assistance, it would encourage the (6/15) participants (similar to the honey-pot effect observed with the Opinionizer display by Brignull and Rogers, 2002). This, however, is not based on observed behaviour and should be taken as an expectation that unfamiliar technology can cause such barriers. These barriers can then be lowered by observing that, for instance, using displays to receive navigation support is the accepted norm in that environment.

In contrast, (8/15) participants felt that the displays were there to be used and owners must have an expectation of navigation-related interactions to take place outside their offices. Two participants (2/15) commented that they would, however, be attentive of the office occupant's behaviour, in case they showed any signs of discomfort or being disturbed.

"If they were constantly working and they kept looking up as if they were going to come in to the office or something like that it might be uncomfortable"

7.2.3.2 Privacy

Although none of the participants experienced privacy issues during the study, (7/15) participants anticipated privacy concerns in sensitive environments. For instance, three participants suggested (during the semi-structured interviews) that confidentiality of navigation was essential in hospitals and even educational institutions. Another participant felt that it was unnecessary for others know his destination or to become involved if he is lost. One participant was also concerned whether the display owner would have access to the information that she is viewing on the display (e.g. who she's looking for).

"…not everybody would want them to know that they were going to the gum clinic or something embarrassing"

In sensitive locations, (7/15) participants suggested that personal devices such as mobile phones were ideal for receiving navigation support. One participant drew the analogy of using a mobile phone as following directions written down on their hand.

Interestingly, one participant stated that directly interacting with the situated display also created a personal space for them. In many ways, the public nature of the displays becomes more personal (and private) once users are interacting with them. For instance, the directions are personal to users. The medium-sized dimensions of the displays can prevent "shoulder surfing" (Sharp et al, 2006) and allow the display to be less visible to others (even though others may be aware of their activity). Furthermore, corridors are described as transitional spaces (O'Hara et al, 2003), which people use to reach other places. Thus, there is less likelihood of idle bystanders. This gray area of shifting artefacts (things created, manipulated and owned by a user or group) between public and private has been previously studied by Greenberg et al (1999) who state that the shift is based on criteria such as the artifact's user, its proximity to others, visibility of information, and social conventions.

"You feel like that little screen is yours and you're finding out your route. I think it [directly using the display] also keeps it a bit more private"

One participant in particular expressed concern about interacting with situated displays with his mobile phone in sales-oriented environments such as shopping centers. For instance, he was suspicious whether personal data (e.g. phone number) from his mobile phone would be obtained resulting in receiving sales-related text messages (or spam).

7.2.3.3 Device-Related Preferences

There were different device related preferences for: (1) getting directions, (2) receiving en-route assistance, and (3) receiving assistance when lost. For instance, all participants stated that it was useful to get directions from the kiosk display. A large touch screen display in a public location is often a familiar sight as a reference point for information. Similarly, the situated displays also enabled all participants to successfully receive directions (i.e. to the second location in the study).

"I'm used to this for example at the doctors, I check myself in using a similar display"

The mobile phone was preferred for receiving en-route assistance for various reasons. For example, (6/15) participants stated that it was unnecessary to interact with the situated displays whilst walking to a destination location considering the route presentations were available on the mobile phone.

"If you're going to touch a phone to it, I've already got it on my phone, I don't see why I want to then stop and look and use the units along the way, unless it was just the 2D map and I wanted the arrows just to confirm something"

Two participants (2/15) commented that a mobile phone was more familiar and comforting for them. One participant mentioned that stopping to interact with the displays was inconvenient and that it simply made more sense to receive en-route assistance on a mobile phone. Most participants (8/15) agreed, however, that situated displays complemented the mobile phone, especially in potential scenarios where the phone battery might fail and if they are lost. Although this is speculative, the level and rate of power consumption in modern Smartphones makes this a realistic situation. One participant preferred the displays as she was unfamiliar with Smartphones.

"I think if I could just view it on the phone that would be absolutely fine, obviously given the battery life of phones and things like that. I might arrive at the building with no battery, obviously useful to have on the displays as well"

The semi-structured interviews, as well as the think aloud recordings demonstrated that (12/15) participants were reassured by viewing the graphical arrow on the situated displays, for instance, when they were prompted to interact with the first display. Seven of fifteen participants chose to interact with at least one subsequent door display (without prompting by the experimenter) to view localized route presentations. The 3D route and map were viewed five times and the graphical arrow (on its own) twice. One participant commented that the situated displays provided a slightly larger screen compared to the mobile phone, which made it easier to understand. It was also observed that (5/15) participants, without hesitation, ensured that they had arrived at the right location by touching the phone on the display (in tasks two and three).

7.2.3.4 Touch Interaction

The semi-structured interviews revealed that (14/15) participants found it natural to interact with the displays by touching a mobile phone. Six participants compared this form of interaction to having used smartcards in places such as the London Underground and to gain access to restricted indoor locations. It was clear that although NFC technology limits interaction to a few centimeters, the interaction style is well-known. Only one participant felt that the display was slightly unresponsive.

"I liked the fact that, you know if you were lost at any point, you could touch something and interact [to find out you were going the right way]"

7.2.3.5 Localization

During the user study, all 15 participants were only able to view localized route presentations on the situated displays (as discussed in the Experimental Setup section), whilst walking to their destinations. All participants suggested that it would be useful if the route presentations on the mobile phone also updated after touching a display tag. Two participants accidentally restarted the 3D route whilst walking to their first destination, so that it started from the reception area. In this case it would be useful to touch a display and have the phone relocate the 3D route to the user's current position, that is, the starting frame would be indexed to outside the office where the visitor was currently standing.

The (6/15) participants who felt it was inconvenient to interact with the displays stated that they would find it useful to receive localized support without needing to touch the NFC tag. Three participants suggested that a moving YAH marker would be helpful on the mobile phone map. Similarly, (10/15) participants stated that a useful feature would be to receive a prompt on the mobile phone if they went the wrong way (e.g. through a vibration or visually).

7.2.3.6 Display Type and Route Presentation

We were interested in exploring the ways in which users prefer route directions to be presented on the kiosk display, mobile phone and situated door displays. For the smaller mobile and door displays, (4/15) participants felt that the display space must be fully exploited by each type of route presentation. Splitting a smaller screen to show the 3D route and a map (with a corresponding moving YAH marker) at the same time would be confusing and it would waste space. This would, however, be a useful option for the larger kiosk display.

7.2.4 Summary

This study investigated the social dynamics surrounding the interaction with an existing shared display deployment, and the interaction preferences of users towards our navigation system, in particular the interplay between mobile and situated displays. Our key findings can be summarized as follows.

- The portrayal of ownership associated with the shared displays caused various study participants to feel uncomfortable, despite the displays' availability for supporting navigation-related activity. The semi-structured interviews revealed that display interaction is shaped around the observable display owner's behaviour and the perceived accepted social norm in the environment.

- Our study revealed that participants anticipate privacy concerns of their navigation task in sensitive environments such as hospitals. While personal mobile phones are ideal in these circumstances, we also believe that the medium-sized dimensions and placement of the situated displays in transitional spaces (e.g. corridors) help create a private space.
- Structured display configurations equipped with passive NFC tags can be pre-configured to provide location and orientation information. This approach reduces the complexity of dynamically computing location/orientation information. However, it limits the availability of displays to specific locations, thus affording the need for additional displays.
- It was apparent that situated displays can usefully complement mobile phone functionality by providing an additional source of reassurance, a larger screen that mitigates mobile display size limitations, and an alternative resource to a mobile phone (e.g. for inexperienced Smartphone users).
- Mobile phones can be used as unique identifiers to immediately receive personalized navigation support from situated displays. While this approach addresses the multi-user scenario, it also limits the interaction to social protocols such as turn-taking (although turn-taking can complement the portrayal of the accepted social norm in the environment).

7.3 Discussion

The user studies described in this chapter provided insights into: (1) user interaction preferences and requirements for client devices and route presentations (2) the social issues surrounding the use of existing shared displays, and, (3) user interaction and contextual factors surrounding the interplay between mobile and situated displays.

7.3.1 Customization

Study five showed the importance of supporting customization of route presentations on personal mobile phones. For example, this involved the requirement of controls for adjusting the playback speed of the 3D route visualization and ways of switching between route presentations. In contrast, participants did not suggest any preferences or requirements for receiving support on the kiosk display. It can be argued that the importance of customization is related to the personal nature of mobile phones (whereas kiosk displays are more public) and the sense of ownership that it affords. For example, in study six, one participant (1/15) drew the analogy of using a mobile phone as following directions written down on their hand. Designers of Nokia phones suggest that "…the personalization of the mobile phone may play an important role: The constant use of the mobile handset becomes a very personal object…" (Vananen-Vaino-Mattila and Ruuksa, 2000). In addition, navigating to a location is a much more complex task in comparison to simply getting directions to the location. Two participants (2/15) in study five, who chose to view the map whilst walking to their destination, would prefer it if they were in control of rotating the map. Again, it was evident that the elements of control, as well as customization, are important for mobile phone use.

7.3.2 Privacy

An interesting topic that emerged in user study six, during the semi-structured interviews, was the privacy of navigation tasks. Although none of the participants experienced privacy issues, (7/15) participants stated that it would certainly be a concern in sensitive environments where they would prefer their destination to be confidential (e.g. in hospitals). In these circumstances the personal element of mobile phones was re-iterated by our study participants and their ability to create a private space. We also found that the situated displays can also achieve a similar purpose. The directions presented are personal to the user, the medium-sized dimensions can prevent issues such as shoulder surfing (and restrict visibility of the user's destination to others) and their placement in transitional spaces such as corridors helps reduce the number of idle bystanders. Although only one participant in study six confirmed that the situated displays created a private space and given that others might be aware of the user's activity, this gray area between public and private associated with the situated displays raises interesting implications for exploring its use in more sensitive environments. An interesting avenue would involve exploring which elements of the display interaction (e.g. user's destination) are known and/or visible to a potential shoulder surfer.

7.3.3 Reliance on Technology

It was also observed and discussed during the semi-structured interviews during both studies five and six that participants were reliant on the mobile phones and the situated displays rather than their own sense of direction. For example, in study five, (12/16) participants commented that they already had a rough idea of their route after receiving directions on the kiosk display, but it was nevertheless observed that they were following their phone. In study six, one participant stated:

"The technology partly turns off your brain a little bit because you know you can always rely on it than actually thinking".

The reliance on viewing route presentations on devices echoes the ideas of externalization, which is an underlying principle in activity theory (i.e. internalization-externalization). It is clear that the activity of being directed to a location is distributed externally, in this case, through the use of the route presentations on a device.

7.3.4 Mobile and Situated Display Interaction

A key observation that was made during study five was that the fixation on mobile devices can reduce interaction with the environment, thus impacting situated display interaction. Similar findings have been previously observed by Muller et al (2008) and Rukzio et al (2009). Even though participants were informed in the fifth study prior to walking to their destination about the purpose of the displays, they were overlooked by (7/16) participants. Thus, in user study six, it was necessary to prompt all participants. The implication here is that situated displays are perhaps more suitable as a secondary source of navigation assistance if the user is already receiving support from a mobile phone.

In the sixth study, we aimed to investigate the potential of location-aware support through mobile and situated display interaction, while at the same time receive further insights towards the interplay between them. The interaction style was effective as (14/15) participants found it intuitive to be able to touch a phone to a display and immediately view a graphical arrow pointing them in the right direction. The touch interaction was compared by our study participants to, for instance, previously touching an Oyster card to a terminal in the London Underground. However, despite employing a useful, as well as a lightweight, interaction technique between the mobile phone and situated displays, (6/15) participants stated that having to stop and interact with the displays was inconvenient and that they would prefer to view localized route presentations on their mobile phone.

7.3.5 Portrayal of Ownership

In study six, although a large number of participants (9/15) felt comfortable using the displays, the portrayal of ownership can be a barrier for users who might find the interaction intrusive or embarrassing. It was also clear that the lightweight interaction technique which enables users to quickly view an arrow and walk away, did not reduce discomfort for (6/15) participants. This issue raises interesting questions about how the existing deployment can be adapted. For instance the placement of the displays is useful for the messaging application as visitors wanting to leave a message can identify whom the display belongs to. The (6/15) participants who experienced discomfort suggested placing the displays on opaque surfaces or public spaces. However, this would then remove the suitability of the messaging application. Thus, the availability of the displays for visitor navigation must be clearly advertised and/or additional displays deployed.

7.3.6 Activity Model Analysis

The findings from studies five and six have revealed the complexities surrounding interaction between mobile phones, situated displays, and route presentations. Whilst it is a challenging task to design a navigation system which meets every single user requirement and preference, these studies have provided insights from a user-centered approach into a number of important factors. Figure 34 below presents the activity model in relation to user interaction with the navigation system components.

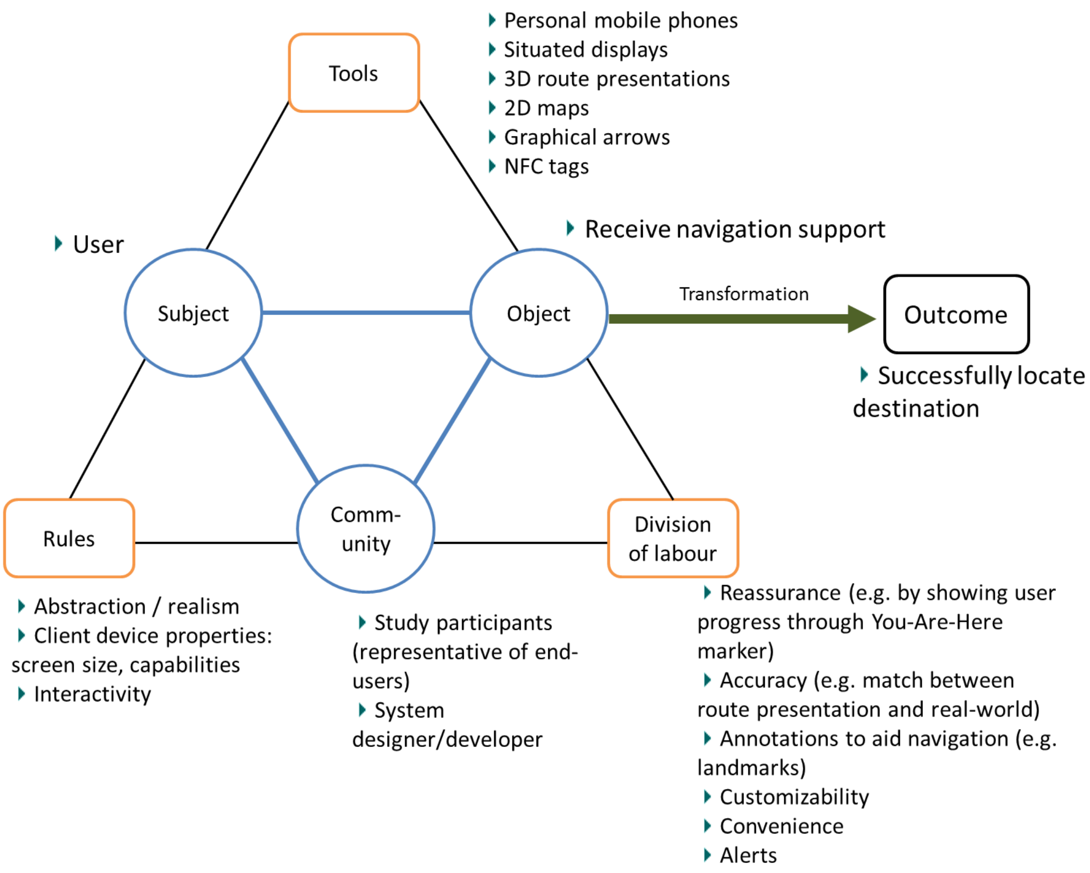


Figure 34 - Activity model at the interaction level showing the relationships between combining devices and route presentations to support visitor navigation.

The model shows that certain rules (or constraints) mediate whether users successfully locate their destination, including: mobile phone capabilities for media playback and NFC interaction, the types of interactivity allowed with the route presentations, and levels of abstraction portrayed by the map and 3D route. In addition, the users' success in locating their destination is mediated by the division of labor. More specifically, this relates to the level of reassurance that the route presentations provide them, the level of accuracy portrayed in the route presentations, whether the annotations are useful, the convenience of interaction styles (e.g. mobile and display touch interaction), the level of customizability allowed by the route presentations, and whether the system aids users by alerting them if they have deviated from their route.

The findings from study six concerning the environmental aspects surrounding the use of the prototype navigation system are illustrated by Figure 35 below. The model shows that user interaction with tools (e.g. situated displays) is mediated by rules such as: whether users are prone to social embarrassment, how familiar users are with client devices, the sense of ownership attached to the client devices, whether users are in a sensitive environment, and the portrayal of ownership and access by the situated displays.

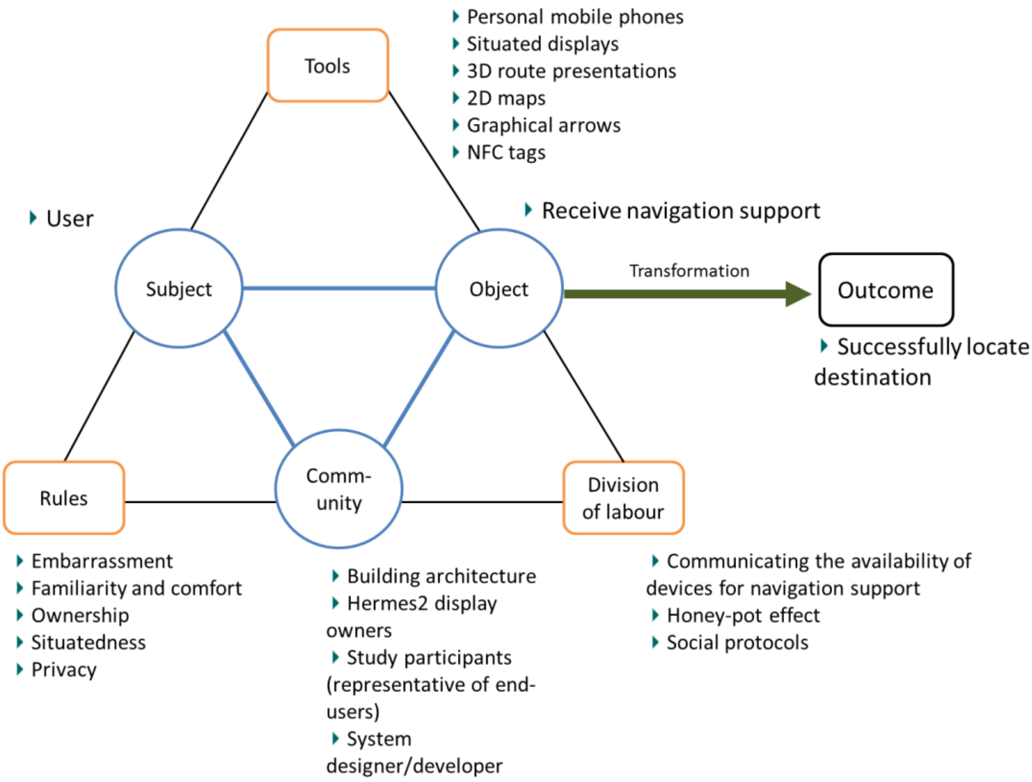


Figure 35 – Activity model at the contextual level showing the relationships between combining devices and route presentations to support visitor navigation.

Designers must also adequately communicate the availability of resources that are able to provide navigation assistance to users. In study six, (4/15) participants felt that they would feel more comfortable interacting with the situated displays if they were informed of their purpose at the beginning of the navigation task. Although all study participants were informed regarding their purpose (e.g. by the task sheets, and by prompting them to use the first display en-route), a different strategy was possibly required. Study six also revealed that (6/15) participants who felt uncomfortable using the displays would be more encouraged to do so if they saw others using the displays for navigation support (i.e. similar to the honey pot effect described by Brignull et al, 2002).

In many ways, the insights received towards mobile and situated displays from studies five and six can be supported through the principles of activity theory. It is clear that the development (over time) of mobile phones as a personal artifact affords the notion of ownership and is able to provide benefits such as comfort, customizability and privacy. In contrast, the way in which a visitor may have developed their attitudes towards public displays is more variable. For example, it is likely that users have mainly been exposed to information displays in public locations rather than, for example, a personal device in private locations.

The reliance on technology observed during both studies five and six can also be compared to the reliance on other means of navigation assistance, such as printed maps and on-the-wall signage. Navigation can be regarded as an activity which is dynamically distributed in the internal and external domain (i.e. following the principle of internalization-externalization). When a visitor is provided with instructions for the first time, they will attempt to externalize their internal thought processes by matching descriptions and using external environmental cues in order to achieve their goal (locate their destination). In the context of mobile devices showing route presentations, it can be argued that the process of navigation is continuously externalized on the device. For example, the user may rely on the device to inform them that they have taken a wrong turn rather than using their own judgment. As the map shown on the mobile phone in our studies did not utilize a moving You-Are-Here marker to show continuous progress, we observed that participants typically matched room numbers from the map to the physical environment. However, if such a feature was included, we may observe that participants would not find it necessary to match room numbers and that they simply follow the You-Are-Here marker (and in turn, utilize less internal resources).

7.3.7 Limitations

The studies described in this chapter aimed to address a number of limitations that were faced in the previous user studies, which have been described and discussed in chapters five and six. However, similar to the previous user studies, we explored a scenario where participants were exposed to various conditions that may affect their requirements and preferences. We anticipate that observations in the wild would enable us to observe users in more varied conditions such as time-pressure. Furthermore, in the sixth study, participants were not provided the benefit of receiving location-aware support on their mobile phone. Thus, it becomes difficult to deduce whether this would, for instance, make users more comfortable interacting with the displays.

7.4 Chapter Summary

This chapter has described two user studies which have investigated: (1) interaction preferences of users towards personal mobile phones, situated displays and route presentations, and (2) the contextual factors that surround the use of the prototype navigation system, which help shape user interaction. It was found that the study participants generally favored the use of mobile phones for receiving en-route navigation assistance, due to their familiarity and the comfort provided by their everyday use. The situated displays were, however, regarded as a useful alternative and an additional source of reassurance. Study six also demonstrated the potential of using the displays as positioning tools through Near Field Communication technology to achieve location-aware navigation support. Finally, we found a number of complex social aspects surrounding the use of the situated displays, such as the portrayal of ownership and the accepted norm towards their use in the environment.

The next chapter provides a discussion of the six formative user studies described in the work of this thesis and brings together the important themes which have emerged.

Chapter 8

Discussion

The previous three chapters have described six user studies that were conducted over a period of four years. These studies have utilized a user-centered approach and sought to gain understandings into the interactional and contextual aspects of the prototype Hermes2 navigation system. The navigation system was incrementally prototyped in order to focus on increasing (as well as overlapping) functionalities of the system. The objective was not to develop a polished and finalized product, but to utilize the prototyping approach as a means of gathering ideas and user requirements. These are intended to inform the design and development of similar navigation systems to the extent where user needs are closely met, and the designers are aware of the types of interaction and context related issues that can emerge.

Further to the insights gained through the user studies, we explored the potential of adapting non-navigation specific existing technology and have developed a deeper understanding of the responsibilities and issues that emerge from managing a ubiquitous display system. This chapter discusses the findings and experiences based on the prototype navigation system. Furthermore, this chapter provides a framework for developing similar useful and usable indoor navigation systems. The framework is based on the activity theory framework, and is expressed through interrelated activities that are essential to the central activity, that is, the development process of the system. The activities are designed to provide an overview of the relevant factors that are necessary for indoor navigation system development, and they are in turn expressed through a number of interaction guidelines and implications that are based on the findings from the user studies carried out as part of the research in this thesis. Following this we describe the generalizability and the limitations of our research methods, as well as reflections on the effectiveness of the methods.

8.1 A Framework for Indoor Navigation System Design

An important part of the research described in this thesis involves the analysis of our findings by using Engestrom's (1987) activity model. The use of activity modeling in this thesis has aimed to provide a structured overview of the interrelated factors that emerged from the findings of the user studies. The central unit of analysis, or activity, is the design and development of the Hermes2 indoor navigation system (as shown in Figure 36), which then branches out and combines a network of interrelated activities (e.g. adapting existing technology, designing route presentations, etc.), which have been described in chapters five, six and seven. In other words, the design of useful and usable indoor navigation systems must consider various factors and challenges that surround the design of route presentations, adapting existing technology, addressing user motivations and patterns of use, and the constraints and conventions within the deployment environment. We believe that this representation of our findings by using an activity model network provides a useful and novel framework for designers of indoor navigation systems. In particular, this framework aims to address the gap in literature which has limited understandings of a user-centered design and development process of indoor navigation systems.

The design and development of indoor navigation systems involves a number of key components, which we believe to consist of the system developer(s) (subject), the development process itself of the system (object), and the deployment environment (community), which includes the system developer(s), user study participants (representative of end users), the Hermes2 display owners, the building owner, and the receptionist. The research described in this thesis demonstrated that carrying out user studies can be an effective means of uncovering insights and understandings that contribute towards the design and development of a useful navigation system. Although this research did not focus strictly on development, study participants are still considered an essential part of the community with regards to informing the development process. The community also includes the Hermes2 display owners, as they would stipulate whether or not their display is enabled for supporting visitor navigation.

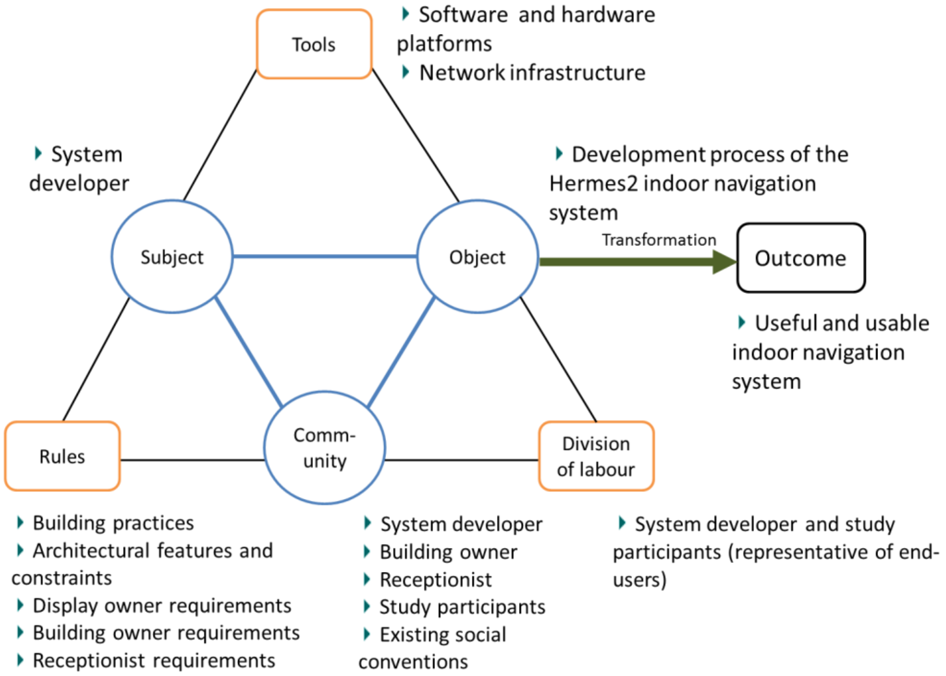


Figure 36 – The central activity representing the design and development process of the Hermes2 indoor navigation system.

The involvement of display owners is also justified by the status messages on their displays, which is beneficial for visitors in determining their whereabouts. Furthermore, an indoor navigation system deployment would require consent from the building owner (e.g. to obtain floor plans and create structural modifications) as well as from the receptionist, whose role already involves directing visitors. Figure 36 represents the navigation system development process activity, that is, the central activity of our framework.

The subject-object-community relationship is mediated by further relationships, as introduced by Engeström (1987), such as the division of labour between the system development process and the community, rules that developer (or subject) has to adhere to in relation to the community, and the tools that enable development process. In more detail, the division of labour is shared amongst the system developer(s), the study participants, and the Hermes2 display owners. The rules include the existing social conventions (e.g. as Infolab21 is an office environment, using audio for navigation assistance may be disruptive), architectural design constraints, and the satisfaction of the building owner and the receptionist for making modifications to the building for a navigation system, and introducing new practices for directing visitors. The installation of the Hermes2 display infrastructure, for instance, involved the removal of floorboards to install cabling and single board computers for each display, which initially required consent from the building owner. Finally, the tools that mediate development process include software and hardware platforms (e.g. off-the shelf CAD software, the open-source GtkRadiant application used for modeling the 3D route visualizations, application development environments, servers, the Hermes2 displays) as well as the existing network infrastructure (i.e. Wi-Fi access).

The central activity that represents the development of an indoor navigation system is related to a set of four activities that have been described in chapters five, six, and seven. These include motivations for receiving navigation support, the feasibility of integrating existing technology, the interaction preferences and requirements for using the navigation system components, and the contextual implications of their use. Figure 37 below shows the way in which the central activity is related to these activities, which have been discussed in more detail in their respective chapters. Therefore, each component shown in Figure 37 is a simplified representation of a set of more detailed relationships.

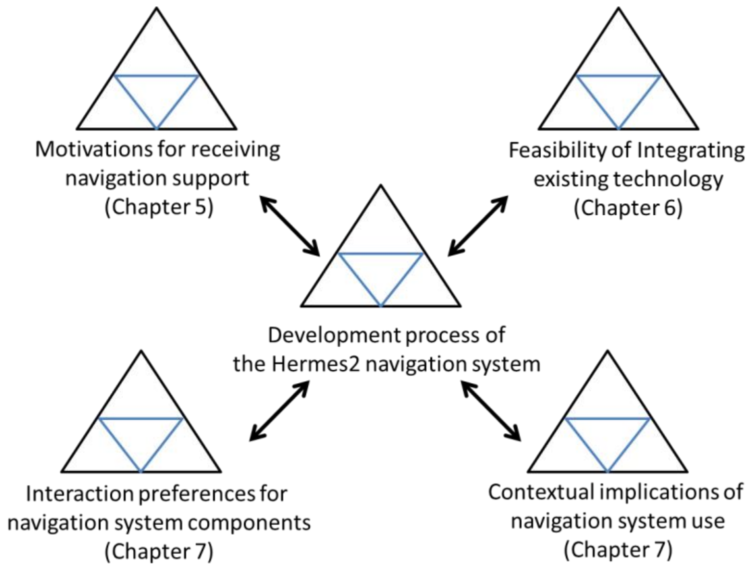


Figure 37 - Activity network showing the interrelated components that contribute to the development of the Hermes2 navigation system.

The next few subsections provide a number of interaction guidelines and implications that are categorized according to the surrounding activities represented in Figure 37 and based on the insights received from our user studies.

8.1.1 Motivations for Receiving Navigation Support

It was clear that user motivations for selecting route presentations were shaped by strategic factors, opportunism, and past experiences, all of which contribute to the importance of providing the availability of accessing both the map and 3D representations. In the preliminary study, and studies one and three (where participants were able to choose the route presentation of their preference on the kiosk display), it was found that (11/24) participants used a strategic approach where they viewed the map in order to gain an understanding of the building's layout, and the 3D route to become familiar with their particular route. It was also clear that user motivations for selecting route presentations were opportunistic and biased towards 3D route visualizations by situational factors such as novelty. A potential limitation of relying on the 3D route is that once users physically deviate from their route, or if they wish to explore other areas, the 3D route becomes unhelpful. In such cases reverting to an overview of the environment (i.e. through a map) is required. Similarly, participants who had chosen to view only the map (6/24) were later shown the 3D presentation and found that it would have been more useful. Another important facet that shaped user interaction with route presentations involves users' past experiences. For example, in the preliminary, first and third studies (8/24) participants did not choose to view the 3D route presentations as they felt it might be too confusing or complicated, and that they were simply more familiar with maps. However, during the semi-structured interviews, they suggested that the 3D route was simpler than the map, and would have helped more. Therefore, it was clear that users may not always make the optimal decision, and that it is necessary to allow users to interchangeably access maps and the 3D route.

Indoor navigation systems would benefit from using 3D representations as the main form of route presentation, but with a clearly communicated technique of switching to a map-based presentation. Across the user studies it was found that the 3D route visualizations were favored in comparison to the maps. However, to keep with the previous design guideline, it is important to enable users to utilize both route presentations. For example, in user study five, participants suggested using an icon overlay. The preference for the 3D route visualizations is mainly driven by its novelty aspect. Furthermore, a key benefit of 3D models is their ability to realistically represent environmental features in contrast to more abstract representations provided by maps (which in turn, utilizes more cognitive resources). Participants generally favored the use of the 3D route visualizations for receiving directions to their destination (e.g. on the kiosk display) as well as on their mobile phone whilst walking to their destination. For example, in study five, (14/16) participants chose to view the 3D route visualization on their mobile phone (after having been exposed to both presentations on the kiosk display). Discussions with participants in study six further indicated that 3D presentations were generally favored.

Designers need to be aware of the cultural characteristics of route presentations that can influence user motivations towards their usage. Insights towards the cultural factors surrounding the use of maps and 3D representations emerged from the preliminary study and studies one and three relates. For instance, the 3D route visualizations either provoked curiosity and interest or were regarded as confusing and complicated. Maps were seen as familiar and therefore comfortable to use, or generally confusing and uninteresting. The explanation to the “why” aspect can be understood by regarding route presentations as artifacts which carry particular cultural and historical characteristics (Nardi, 1996), which are also subject to development over time (i.e. as discussed in the context of activity theory). The reasons behind the preconceptions can be attributed to factors such as past experiences and usage. For example, in the preliminary and first user study, (9/14) participants wrote down video games, which are not tailored for supporting navigation, as their previous experiences with 3D environments (i.e. in the questionnaires). One participant in the first study stated that the You-Are-Here maps in the Lancaster University campus were unhelpful and non user-friendly. Furthermore, current commercial navigation systems mainly utilize map-based representations (e.g. in-car GPS systems), and existing indoor navigation systems in published literature make little use of 3D representations. Thus, exposure to 3D representations for navigation is limited and can be regarded as novel. In contrast, the unfamiliarity with 3D presentations can limit user interaction and cause them to choose what’s familiar (i.e. a map).

8.1.2 Feasibility of Adapting Existing Technology

It is imperative that the integration of existing technology addresses the requirements of its primary users who control most of its functionality. An important requirement for adapting the Hermes2 deployment for the purposes of supporting visitor navigation was to investigate the impact it could have on its display owners, who control most of the display's functionality. Thus, it was necessary to carry out a questionnaire study (i.e. study two) in order to establish whether the primary users (display owners) were willing to share their displays for the purposes of assisting visitor navigation. This enabled us to determine and address display owner requirements such as using a transparent (in terms of opacity) approach to displaying navigation-related content and the ability to customize whether certain features (e.g. whether their display message is shown on the kiosk display at the reception area of the building) can be enabled and disabled, for instance, through a web-portal. The findings from the questionnaire suggested that the design of an indoor navigation system that integrates a deployment such as Hermes2, must provide additional functionality for its primary users (i.e. display owners). If display owners are using an application to communicate with the display, then the navigation system developers would need to either make amendments to the application, or otherwise develop a new application (e.g. a web portal) where display settings can be customized for enabling visitor navigation support. In a scenario where display owners choose to opt out from allowing their displays to show navigation related content, then it would be necessary to communicate that the displays are unavailable for visitor navigation. This would allow users to distinguish from displays that they can use and those that they cannot.

Navigation application designers who might choose to utilize similar in-building display deployments must be aware of the structural constraints that surround them.

Another challenge of using the Hermes2 deployment was developing a navigation system that was based around the structure and location of the situated displays. The deployment has a pre-configured structure which limits the displays to specific locations (i.e. there are locations without displays where they are required for navigation support). Furthermore the placement of the displays (i.e. next to the display owner's office door) is tailored around its original messaging application. The sixth user study showed that (6/15) participants were uncomfortable with the display placement. In such cases, additional measures need to be put into place which addresses these challenges, such as informing users of their purpose and by the use of additional purpose-built displays to complement the existing deployment.

We also believe that the challenges faced with the management of the Hermes2 display deployment (hardware failures and the decline in the usage of the messaging functionality) can be useful for informing designers of the types of technical issues that can emerge and the types of maintenance tasks that are necessary. For example, maintaining user satisfaction is a very challenging task once a deployment begins to experience technical faults. If these faults repeatedly occur, user trust with the system declines over time, which means that the level of usage also declines. If, for instance, the Hermes2 display owners were not setting messages on the displays, then the role of utilizing these messages to assist visitor navigation (i.e. by allowing visitors to be aware of the display owners activity) becomes ineffective. Furthermore, the importance of notification services is crucial to the maintenance of such a deployment. These services must be able to detect both hardware and software-based faults, which then must be immediately resolved to avoid complaints. The Hermes2 system included a Java-based service which detected boot-related faults, as well as a software-based service which sent out notification emails to an administrator mailing list with details of the specific display and the type of error. As a contingency plan, there must also be a means of remotely monitoring the system (e.g. in case the notifications fail). Regular inspections of the system are also necessary, which involve detecting hardware issues which cannot be detected by automated software services. An example of this is the overheating issue experienced by the Hermes2 displays, which caused the VGA chips on the display circuit board to overheat and cause a classic blurry screen.

A key challenge with situated display deployments such as Hermes2 is the impact of technological shifts over time. One of the technical issues faced with the Hermes2 system was the aging of technology, which led to hardware faults as well as issues with keeping up with technological shifts. For example, the Hermes2 displays currently support resistive screens (which are tailored for styluses), however, developments in touch-screen technology have replaced resistive touch screens with capacitive screen, which are far more responsive. Therefore, user expectations can be affected such that they might believe the display is unresponsive.

8.1.3 Interaction Preferences for Navigation System Components

The navigation system components that were investigated in the user studies described in this thesis involves route presentations such as 3D route visualizations, 2D maps, client devices such as mobile phones and situated displays, and other forms of assistance such as graphical directional arrows and display owner status messages. The following subsections provide interaction guidelines and implications for using specific components, as well as a combination of components.

8.1.3.1 Route Presentations

The review of published literature carried out in chapter two has demonstrated the technological feasibility of various route presentations and their ability to generate optimal routes and to accurately determine the user's current position. In addition, research from cognitive psychology has discussed the benefits of various route presentations (Siegel and White, 1975; Holscher et al, 2007). For example, graphical signage is easy to follow due to the low cognitive requirements, maps provide survey-based spatial knowledge, and 3D environments aid in the development of familiarity with the environment and route knowledge (and eventually survey knowledge through prolonged exposure). However, it is not a simple task to design route presentations for a navigation system so that user interaction requirements are closely met. The user studies described in this thesis aimed to expand on the past understandings of designing route presentations and to gain insights towards user interaction preferences, requirements, motivations and the impact of the system's deployment environment on user interaction. In particular, we focused on the combined use of maps, 3D route visualizations and graphical directional arrows.

It is important that route presentations incorporate features such as alerts and annotations to ensure that users feel reassured along their route. While combining two and three-dimensional representations are beneficial, other methods of reassurance must be provided through alerts, annotations and visual display of user progression. Being lost in a complex multi-level building is an unpleasant experience which can cause feelings such as anxiety. One participant from study six stated that "*half the anxiety of going somewhere like that is not being able to find [your location]"*. Further issues with orientation due to changes in direction can be caused once users have traversed a set of stairs or taken the elevator (Montello and Pick, 1993). For example, one participant in user study five (described in chapter seven) stated that he had become disoriented once he was at the top of the first set of stairs. In terms of the providing reassurance, participants in studies five and six suggested that a useful system feature would be to alert them (e.g. through vibration or audio) if they have deviated from their route. Both studies five and six also highlighted the need for continuous location-aware updates on route presentations whilst walking that shows their progression along the route (e.g. through a moving You-Are-Here marker). In addition, digital representations have the benefit of aiding navigation through route annotations. For instance, it was found that enlarging door signs and including landmarks in the 3D route, as well as annotating the start location, the user's route, and destination location in the maps, were useful contributors to reassurance.

It was clear that digital signage such as graphical directional arrows was an effective tool that can be dynamically adapted to various destination locations and can also reassure users along their route. The general advantage of signage is that they demand less cognitive resources in order to communicate directional information (Holscher et al, 2007). Furthermore, in a structured indoor environment it can be argued that only a set number of signs are required (e.g. left, right, turn-around, straight ahead, etc.) and once a location model is utilized with a digital navigation system, the signs that are appropriate to a user and their destination can be shown on a digital display. In study six, location data stored on passive NFC tags enabled users to view signage at any situated display along their location, as opposed to static printed signage which is less ubiquitous. However, the limitation here is that only display devices would be able to communicate digital signage. In addition, studies five and six demonstrated that graphical arrows on the situated displays provided supplementary reassurance to users whilst they were en-route. In study five, (8/16) participants suggested that the graphical arrows were important in reassuring them that they were walking in the right direction. In particular, two participants (2/16) were explicitly reassured by the arrows on the displays when they were unsure of their location at a specific point in their route.

Reassurance can also lead to reliance; therefore designers of navigation systems must ensure that accurate environmental representations and navigation cues are provided on route presentations. The relationship between reassurance and reliance can be better understood using the principles of mediation and internalization-externalization, which are key elements of activity theory. For instance, finding one's way in an unfamiliar environment using only memory as a guide requires a dynamic distribution and re-distribution of internal and external activities. The directions may have been internalized from external instructions. However, users need to utilize the external components of the environment, such as landmarks and room numbers in a building, in order to match their internalized descriptions. On the other hand, a route presentation provides a tool which can be used to mediate the entire process and make it more efficient. If we consider a simple printed map, users have with them a representation of the environment which can be referred to. However, a map still requires activities such as scale translations (Montello and Freundschuh, 1995).

By digitizing a map and introducing interactivity such as dynamic position updates that also portray orientation, users are then able to use a tool which is externalizing the entire process. Hence the activity of navigation becomes highly efficient and requires minimal mental processing. A drawback of this behaviour can be attributed to the lower quality of cognitive map development, due to lack of internalization. This echoes the findings of Willis et al (2009), who found that users who follow mobile phone instructions (e.g. a map) switch off and become passive receivers of information. Inconsistencies with information provided on route presentations contain the risk of causing the user experience to quickly decline. This can already be observed with drivers who become frustrated at their GPS system for "taking them the wrong way" or "making them lost".

An important facet of designing route presentations is their ability to support customizability and control, especially on mobile phones. In study five we found that (11/16) participants wanted to control the playback speed of the 3D route visualization, for instance, through a slider. However, it was found that this requirement was only preferred for mobile phones and that study participants were satisfied with the playback speed of the visualization on the Kiosk display. In terms of the maps, both manual and automated (by the system) rotation were suggested. In this case it is important to develop a feature which would allow users to select rotation type based on their preferences.

An additional feature that was highlighted in study five was the requirement for intuitive techniques of switching between route presentations on the mobile phone. These included suggestions such as switching mediated by a clickable icon on each presentation, choosing a specific point on the map (e.g. along the user's route) from which the 3D route visualization would play, and simultaneously viewing both route presentations.

8.1.3.2 Client Devices

Mobile devices and situated displays have mainly been studied in terms of their technological feasibility and performance through the development of novel indoor navigation systems. In particular, mobile devices have been crucial for enabling location-aware (and also context-aware) navigation support. Current advances in Smartphone technology, for instance, are allowing higher positioning accuracy through the integration of sensors (e.g. accelerometers and digital compasses). Furthermore, systems such as Smart Signs (Lijding et al, 2006) and the Rotating Compass (Rukzio et al, 2009) have investigated the use of situated displays showing digital signage coupled with mobile phone use. There are, however, limited insights towards user interaction and the cultural significances that help shape user interaction.

Mobile phones are useful artifacts for mediating reassurance to users by enabling them to constantly refer back to route presentations whilst walking to their destination. One participant in study six, for instance, commented: *"[I would prefer receiving navigation support on a mobile phone] because I like playing on my phone and I'm a lot more comfortable with things on my phone. And obviously, it's more mobile so"*. A mobile phone can be regarded as an artifact (or tool) that mediates the object (as referred to in activity theory) of locating a destination. Activity theory supports the notion that artifacts carry with them physical, cultural and historical characteristics. If we examine the cultural significance of mobile phones, we can observe that they are devices designed for personal use. The ubiquity of mobile phones in our day to day lives also makes it a familiar technology, which in turn can create comfort.

Route presentations shown on situated displays can usefully complement the use of mobile phones by providing additional reassurance to users. The user studies provided a number of insights towards the benefits and limitations of using situated displays to support visitor navigation within building environments. In user study five, it was clear that the displays provided an additional source of reassurance for participants. In particular, two participants who experienced confusion whilst viewing route presentations on their mobile phone felt reassured when they noticed the situated displays showing a graphical directional arrow (indicating that they were going the right way). It was also found that participants across the user studies found the kiosk display useful as a reference point, for instance, if they have just entered an unfamiliar building. An interesting observation that emerged from the user studies was that participants had no requirements for customization or control of route presentations on the kiosk and situated Hermes2 displays. If we re-examine the idea supported by activity theory which states that artifacts carry cultural characteristics, it can be understood that unlike mobile phones, public display interaction can be shared amongst groups of users, thus ownership is more distributed (e.g. between system administrators, primary users, secondary users).

Optimal locations for additional situated displays include decisions points and locations that are within the user's field of view (i.e. ceiling or floor). Due to the structure of the Hermes2 display deployment (i.e. they are fixed to specific locations such as beside office doors), it is not possible to relocate the displays. However, we were interested in the locations where, for instance, additional displays would be useful for participants. In studies three and five we found that looking to the side whilst navigating (i.e. walking to a destination) can be somewhat unnatural, and therefore designers can facilitate display interaction by placing them in more prominent locations within the user's field of view.

Ubiquitous situated displays placed in the environment can offer a cost-effective and useful method of providing location aware support mediated by short range NFC tags. This particular technique was successfully tested in the sixth user study. One advantage here is that positioning accuracy through signal measurements does not have to be accounted for, as the displays can be utilized as positioning tools (e.g. through pre-configuration). Another benefit involves the fixed nature of the displays, which can mitigate the requirement for orientation calculations (e.g. through angulation techniques).

Combining Mobile and Situated Displays

One of the key challenges in combining the use of mobile and situated displays for navigation support is the tendency for users to be fixated on mobile phones, thus causing users to overlook displays situated within the environment. For example, in study five, when participants were explicitly informed to use the displays at the beginning of their navigation task (i.e. to walk to their destination), (7/16) participants still overlooked them as they were fixated on the mobile phone. This behaviour has been previously observed during user studies carried out by Muller et al (2008) and Rukzio et al (2009), where it was observed that mobile phone users paid little attention to the environment. It was evident that in order to entice mobile phone users to interact with the displays, methods such as prompts and alerts were necessary. However, we anticipate that this would be disruptive and unnecessary. Therefore, an important role of the displays was to provide supplementary support for mobile phone users whilst they were walking to their destination.

In the absence of mobile phones the displays can be a useful alternative for providing navigation support. For example, one participant in study six stated that they were generally uncomfortable with Smartphones and would prefer to only use the displays. Furthermore, (8/15) stated that situated displays complemented the mobile phone, for example, in scenarios where the battery might fail. Although this is speculative, the rate of power consumption of modern Smartphones makes this a likely scenario. Similarly, mobile phones can complement situated displays by mitigating the absence of situated displays in certain locations (e.g. one constraint with the Hermes2 displays is that they are not placed in all decision points).

The touch interaction technique, which was explored in study six, is a useful method of coupling mobile phone and situated display interaction for indoor navigation support. Study six showed that (14/15) participants found it intuitive to be able to touch a phone to a display and immediately view a graphical arrow pointing them in the right direction. The touch interaction was compared by our study participants to, for instance, previously touching an Oyster card to a terminal in the London Underground. However, (6/15) participants stated that having to stop and interact with the displays was inconvenient and that they would prefer to view localized route presentations on their mobile phone. Thus, there is a tradeoff between benefits of receiving localized assistance and the issues with this particular interaction style. It is therefore necessary to investigate whether extending the functionality of our system to also include location-aware support on the mobile phone would make this technique more favorable. The touch interaction, aided by the mobile device as a unique identifier, enables the system to support multiple users. We predict that in busy environments where display availability might be low, social protocols such as turn-taking would come into effect. Turn-taking can already be observed with public display interactions.

8.1.4 Contextual Implications of Navigation System Use

Designers must be aware that privacy requirements of users' destination locations can emerge in more sensitive environments such as hospitals. Therefore an important guideline for the design of indoor navigation systems is to support the use of personal mobile phones. For example, while the physical dimensions of mobile phones make them ideal for navigation (which itself is mobile in nature), these dimensions are also useful for limiting visibility of content to others, thus preserving privacy. One participant in study six stated: *"I would prefer everything on the phone, because then it's a small screen and only me and people immediately around me can see me, not 10 people who are stood around*".

Medium sized displays placed in transitional spaces such as corridors have the potential to invite more private interactions in sensitive environments such as hospitals. In terms of the physical characteristics of displays, while large public displays may not afford private interactions, one participant in the sixth user study stated that physically interacting with the situated displays created a private space for them. Although our study was not carried out in a sensitive context, the participant's comment raised interesting questions about the potential of allowing more private interactions through medium-sized displays. It is likely that the medium-sized dimensions can prevent issues such as shoulder surfing (and reduce visibility of display content to others) and their placement in transitional spaces such as corridors also helps reduce the number of idle bystanders. Although only one participant confirmed that the situated displays created a private space, an avenue for further work would be to investigate how much information is visible to a shoulder surfer whilst a user is interacting with the situated displays.

Some of the key contextual factors that affect user interaction with the situated displays are their physical location and the social behaviors and conventions that surround it. The Hermes2 situated displays are tailored towards supporting a messaging application, where it is necessary to portray the ownership role to a particular display such that visitors are able to identify, for instance, which display belongs to a display owner. The sixth user study revealed that (6/15) felt uncomfortable using the door displays due to being able to see the display owners through the transparent surface the displays are placed on. The discomfort is also related to feelings of social embarrassment. One participant stated that if a display owner walked out the door and found the participant interacting with a door display, the situation would be embarrassing. Although a large number of participants (9/15) felt comfortable using the displays, the portrayal of ownership (between displays and their owners) can be a barrier for users who might find the interaction intrusive or embarrassing. The (6/15) participants who experienced discomfort suggested placing the displays on opaque surfaces or public spaces. However, this would then remove the suitability of the messaging application. Thus, the availability of the displays for visitor navigation must be clearly advertised (e.g. using signposts) and/or additional displays deployed. Furthermore, (6/15) participants who were uncomfortable using the displays stated that perceiving others using the displays would help diminish barriers and make them feel that it is the accepted social norm.

8.2 Generalizability

Although the use of the prototype Hermes2 navigation system was constrained to the Infolab21 building, the insights gained across the user studies can be applied to other building environments and in real world settings. These include both interaction and context related insights that were gained. For example, reassurance is a common human trait which can be an important requirement in circumstances where users are finding their way in any unfamiliar environment. It can therefore be generalized to other building environments where visitors are unfamiliar with the layout. The cultural characteristics of components such as route presentations and client devices are based on the existing norms within the society, thus designers can examine the types of technologies that the public has been exposed to, and anticipate user motivations of use. For example, a community where interactive situated displays are prevalent would benefit from providing navigation support using similar technologies. In terms of context, it can be asserted that the visibility of public display owners (and therefore the portrayal of ownership) in any environment can cause users to feel discomfort or embarrassment. Furthermore, the type of environment can affect the level of privacy that users might require. For example, if the user studies were carried out in a hospital environment we are likely to find that a number of users would prefer it if their destination was kept private.

Mobile phones play an important role in our day-to-day activities, and it is therefore likely that users seeking navigation assistance in building environments will have a personal mobile phone. The user studies have also investigated an application-free approach to viewing route presentations on mobile phones, which are downloadable from the navigation application using common technologies such as Bluetooth and Wi-Fi. Therefore a mobile phone would only be required to support media playback and internet connectivity. In relation to our investigations with NFC technology for location-aware support, this approach was more constrained as it would apply to mobile phones with NFC capabilities (although it is evident that NFC technology is becoming increasingly integrated into Smartphones, e.g. for making purchases in retail environments, sharing music playlists, etc.).

The Hermes2 displays are specific to the Infolab21 building, however the functionality provided by them for the purposes of supporting visitor navigation can be applied to general public display systems (e.g. kiosk displays, information displays). We anticipate that buildings such as shopping centers, hospitals and university department buildings may already support public display installations. Alternatively, a new deployment of displays can be carried out, but this does not have to match the structure of the Hermes2 deployment. A relatively low-cost touch screen display can be utilized as a kiosk terminal for visitors who enter the building and wish to receive directions to a location. Further displays can be installed at specific locations (if not already installed) such as decision points. In terms of the messaging application supported by the Hermes2 system, our main interest was in the status messages set by display owners. Therefore, a simple application can be developed that would enable building occupants to provide a status message (e.g. through a web-portal) that would aid visitors determine their whereabouts. It is also clear that in any given setting, repeated system failures (e.g. as experienced with the Hermes2 deployment) can lead to breakdowns in user trust. Furthermore, the rapid advances in technology mean that these systems must anticipate these changes in order to meet user expectations.

The development of route presentations such as maps, 3D route visualizations and graphical arrows can be carried out with off-the shelf CAD software and by using existing architectural floor plans of the building. Similarly, a 3D model of a building can be developed using open-source toolkits such as GtkRadiant and by using the Quake 3 game engine. Therefore, we believe that these features can be viably developed, however a software developer would need to implement a navigation application that integrates the route presentations and enables interaction through a GUI.

8.3 Limitations

The approach used in the user studies aimed to approximate a natural setting which sought to gain predominantly qualitative insights towards user motivations, interaction preferences, requirements, and also the contextual implications surrounding the use of the prototype Hermes2 navigation system. One of the difficulties in approximating a realistic setting in user studies is that the behavior of participants is affected by the nature of the study. For example, we found that our study participants did not use existing signage (e.g. printed signs) while they were walking to their destination location. It could be argued that one of the causes for this involved the obligation that participants may have felt in order to fulfill the requirements of the study (i.e. use the digital navigation system). Another limitation concerns the conditions under which participants are subjected to using the system. Conditions such as time-pressure could cause feelings of urgency and therefore impact the type of interaction preferences that users might have. Furthermore, participants were asked to locate specific destination locations, which removed any form of emotional attachment to their goal. For example, if participants were desperately attempting to seek out their course tutor, we anticipate behavioral changes as well as differences in user interaction requirements. In addition, it was likely that participant's behaviors were influenced whilst being followed as they were walking to their destination (as well as recorded using video in studies five and six).

An important feature of indoor navigation systems is their ability to concurrently support various users in busy environments. Our investigations into multi-user support were limited by the nature of the user studies, that is, one participant was involved during each study session. The approach using the NFC tags technically addressed the multi-user scenario and we were able to infer that common social protocols would come into play, such as turn-taking. However, these behaviors were not specifically observed in this context and it would require a fully deployed system where we can observe users in the wild.

Another limitation of our research is that our investigations were constrained to a display deployment which has been specifically implemented in the building environment and supports a messaging application that was developed as part of a research project. However, our insights were not based on the premise that other building environments would support analogous infrastructure and applications. The deployment nevertheless facilitated the process of gathering insights towards user interact and context.

In addition to a very specific display deployment, only a set number of routes were utilized during the user studies that were limited to a specific part of the building. Although study participants were always unfamiliar with their route, their preferences and requirements for interacting with the navigation system may be different if the location was different (e.g. in another building) with varying route complexity. However, we anticipate that these differences may not be significant deviations from our findings, but rather, additional preferences that would be useful towards navigation system development.

One of the most important aspects of our methods involved the semi-structured interviews that were carried out with study participants after they had been asked to carry out tasks. Unfortunately in the preliminary study, as well as studies one and three, the sessions were not recorded through audio or video. A key difficulty experienced during these studies was noting down participant's comments using pen and paper, which was at times very time consuming. Although key insights were uncovered, we were unable to, for instance, transcribe the sessions with each participant in order to perform a grounded-theory based analytic approach to uncover emerging themes. In contrast, studies five and six included both methods of data collection and enabled us to produce a more rigorous analysis.

The hardware failures experienced with the Hermes2 displays meant that display usage became less frequent. This has been discussed in more detail in chapter six. The implication of these issues was that the number of routes that study participants could traverse, which also included working displays, was limited. For instance, the majority of displays on one level of the Infolab21 building were not functional, thus restricting the user studies to the reception area and the next floor up. Furthermore, although the receptionist raised concerns about the deployment of a navigation system, the number of non functional displays would have severely limited a full deployment (which would have enabled observation of users in the wild). While several arduous attempts were made to resolve hardware issues, a number of display units simply needed replacing due to overheated VGA chips, and unfortunately there were limited resources in order to carry this out.

8.4 Critique of Research Methods

The key approach utilized in the research of this thesis involved a user-centered design method combined with incrementally prototyping the Hermes2 indoor navigation system, evaluating the usage of its components through user studies, and analyzing the findings by using methods based on grounded theory and activity theory. The next few sections provide a critique of the methods used in this thesis.

8.4.1 Prototyping and User Studies

The development of incremental prototypes and carrying out formative user studies formed a significant part of our research. By carrying out evaluations at different stages of prototyping, we were able to focus on exploring specific combinations of system functionalities. For instance, the preliminary and first user studies focused on exploring user preferences for the combined use of 2D maps and 3D route visualization. In contrast, the sixth study focused mainly on exploring the NFC-based interaction technique for location-aware support (with less focus placed on user preferences for 2D maps and 3D route visualizations). Carrying out studies that focused on the use of a combination of technologies enabled us to simulate a more realistic scenario (although limited by controlling the tasks that study participants carried out) where users might be faced with various means of receiving navigation support in an unfamiliar building. Furthermore, the approach of carrying out multiple user studies enabled us to observe repeated behaviours and patterns of use, which are generally more prevalent during in-the-wild studies with a fully deployed system. For instance, it was clear that there was a tendency for participants to prefer viewing the 3D route visualization across the six user studies. It was also clear that door numbers provided useful checkpoints for users to confirm their current location whilst they were walking to their destination.

The overall positive feedback received during each of the user studies was useful in that it motivated consequent studies and further development of the prototype Hermes2 navigation system. In particular, the semi-structured interviews proved to be the most useful evaluation method during each study. As the interviews were more alike discussions, participants generally appeared to feel at ease with revealing their preferences and ideas for receiving indoor navigation support. The semi-structured interviews also revealed unexpected findings, such as the discomfort experienced by participants when interacting with the Hermes2 displays due to the visibility of display owners (i.e. in the sixth user study described in chapter seven). Furthermore, issuing questionnaires allowed us to capture demographic data and quantitative data to reinforce design implications, such as the importance of viewing both 2D maps and 3D route visualizations. Questionnaires were also helpful in receiving insights from display owners (i.e. study two, described in chapter five) in terms of display usage frequency and their attitudes towards enabling their display to support visitors by showing navigation-related content such as graphical arrows.

Evaluation methods during the user studies such as think-aloud was utilized to maximize the amount of introspective data gathered (and avoid retrospective reports), however, it was less effective in providing insights during the user studies. Thinking out loud can be regarded as an unnatural action for participants (Nielsen et al, 2002), which was evident during the user studies as participants often had to be reminded to think out loud whilst carrying out tasks. The observations were useful in examining how often users paused along their route and where they were looking (e.g. whether they were looking at their mobile phone, at the situated displays, and/or their surroundings). Similar to the think-aloud process, the observation data was limited in that participants were being followed by the experimenter, and therefore the participants' natural behavior may have been affected.

The data capturing methods during the user studies included a Dictaphone (studies four, five, and six), digital video camera (studies five and six), questionnaires (all studies), and pen and paper (preliminary, first, and third study). While utilizing a Dictaphone proved to be the most useful in capturing data from an entire study, using a pen and paper was less useful. For instance, using a pen and paper based technique interrupts the flow of the semi-structured interview, as well as lacks the means of maximizing data capture. Furthermore, studies five and six involved recording participants with a video camera whilst they were walking to their destination (i.e. to observe at which points participants pause and where they look). These recordings were useful in determining behaviours such as participants' fixation on a mobile phone, and pausing at decision points along their route. It can be argued that recording devices can cause participants to feel self-conscious, and perhaps even more so by a video camera. However, in comparison to noting down important comments and observations using pen and paper, using a Dictaphone, for instance, proved to be the most successful in capturing data.

The aim of the user studies was to replicate a realistic scenario and thus produce ecologically valid findings. However, without fully deploying a system and observing users in the wild, simulating a realistic setting with controlled conditions proved to be challenging. In more detail, if certain features remained unexplored (e.g. in study three, the situated displays were overlooked by the majority of participants), another study was required in order to explore that specific feature. Although this approach caused repetition and became time consuming, it also enabled us to form useful insights with regards to repeated user behaviours and patterns of system use. The frequent hardware related issues with the Hermes2 displays, and the concerns raised with the building receptionist certainly limited the ability to carry out a deployment. Therefore, in such circumstances, it can be stated that a useful method of gathering ecologically valid findings is by carrying out user studies by combining an in the wild approach with controlled conditions.

8.4.2 Hermes2 Deployment Activity Logs

A large amount of data was logged related to administrative and management activities carried out with the Hermes2 deployment by using an online blog. These logs included activities such as addressing display hardware failures (e.g. if a VGA chip failed), passing conversations with display owners (e.g. complaints or requests for features), and logging their messaging activity (i.e. on the Hermes2 database) over a period of four years. Keeping logs was a useful method in understanding the types of technical issues that emerge over time from a display deployment. In particular, monitoring display owner activity in terms of how often they set messages was a useful method of looking at the relationship between issues such as hardware failures and frequency of setting messages over time.

8.4.3 Grounded Theory and Activity Theory

The user studies mainly aimed to gather qualitative data (i.e. through observations, think-aloud data, and semi-structured interviews), as well as demographic and quantitative data (e.g. through Likert scales in questionnaires). The challenge with large amounts of qualitative data is structuring it such that common and important themes are clearly communicated. In order to achieve this, the data gathered in user studies five and six were transcribed and analyzed using a grounded-theory based approach. This method of analysis was successful in determining key themes that were relevant to the research questions that motivated the studies. Although studies five and six adopted this method of analysis, the preliminary, first, and third study involved a less rigorous approach. In these studies, the think-aloud, observation, and semi-structured interview data was not recorded using a Dictaphone, therefore creating limitations in the rage of data collected. Although key observations and participants' accounts were noted down using pen and paper, which led to relevant and important findings, maximizing data capture (e.g. through Dictaphone and video recording) could have led to additional insights. The method of analysis in study four was improved through the use of a Dictaphone, however, as it was a small-scale study (with three participants) extracting key themes from the transcriptions did not require a rigorous approach such as studies five and six (which involved 16 and 15 participants respectively).

The activity theory framework was useful in terms of structuring the findings across the user study. In particular, this framework enabled us to bring together the interaction design guidelines and implications and develop a modified activity theory based theoretical framework for indoor navigation system design (as discussed earlier in section 8.1). The principles associated with activity theory also proved to be relevant with our findings. For example, the notion of development over time is echoed by the finding that mobile phones enabled users to feel reassurance as they have become personal devices over time. Similarly, it is essential to take into account the shifts in user perceptions with technological deployments as issues such as hardware failures lead to lack of trust. In addition, the tendency for users to rely on the mobile devices for navigation support can be attributed to the notion of internalization-externalization in activity theory. As discussed in chapter seven, it can be argued that the reliance is motivated by the externalization of users' routes on a mobile device (such as a map or 3D route visualization).

8.5 Chapter Summary

This chapter has provided a discussion of the findings, experiences and limitations of the research described in this thesis. In more detail, this chapter has combined emerging themes from our six formative user evaluations in order to provide a coherent discussion of user interaction preferences, requirements, motivations, and contextual factors that have been uncovered during the studies. The studies have shown that the development of indoor navigation systems must take into account a number of interrelated and complex technological and social factors in order to match user needs. The experiences over a four year period have also highlighted the challenges in managing a ubiquitous display deployment such as Hermes2 and enabled us to develop insights which are intended to inform designers of similar applications.

The next chapter concludes this thesis by summarizing the findings and re-examining the research questions which have been described in chapter one.

Chapter 9

Conclusions

The research described in this thesis has utilized a user-centered approach with the objective of developing a rich understanding of interactional and contextual aspects of the prototype Hermes2 navigation system. This involved conducting six formative user evaluations using the prototype system during which we uncovered a number of user interaction preferences, requirements, patterns of use, and understandings of user motivations towards the interplay between the components of our system. The prototype system integrated a number of components such as personal mobile phones, situated displays and route presentations such as maps, 3D route visualizations and graphical arrows. Additionally, as social conventions and practices can play a key role in determining user behaviour and requirements, we sought to develop a deeper understanding of the contextual factors that surrounded the use of our navigation system by carrying out the user studies. Furthermore, we demonstrated the feasibility and the extent to which the existing Hermes2 deployment can be adapted for navigation, and reported experience-related insights into the technical and social issues that emerge from the longitudinal management of a ubiquitous display system.

In this chapter, we firstly re-examine the research questions described in the Introduction and summarize them with our findings. Secondly, the contributions made by this thesis into the field of indoor navigation are detailed. Finally, this chapter discusses potential areas of further research and ends with concluding remarks.

9.1 Research Questions

The investigations carried out in the research of this thesis, such as user studies, largely addressed the research questions, and provided a number of important insights into navigation system design and development, the potential and usefulness of adapting existing technology, and the challenges that can be faced with maintaining a situated display deployment such as Hermes2. Research questions one and two were predominantly addressed by carrying out six separate formative user studies that investigated various combinations of navigation system features. Insights into research question three were mainly achieved by long term observations, activities, and data logging. All three research questions are re-visited and summarized below.

1) **In what ways do users prefer to interact with an indoor navigation system that comprises of personal mobile phones, an existing situated display deployment (i.e. Hermes2) and a set of 2D and 3D route presentations in an unfamiliar building environment? What interaction and contextual design implications can be extrapolated from the user preferences?**

The observations and discussions across the formative user studies revealed a number of important insights. It was evident that a combination of route presentations (e.g. map and 3D routes) were necessary to enable users to view both route-based and survey-based spatial understandings, as well as to address their motivations for selecting route presentations, which can be opportunistic (e.g. based on novelty), and/or methodological (e.g. understanding the overall layout, followed by gaining familiarity through a 3D presentation). For example, some study participants found viewing their route in perspective with the 3D visualizations more helpful than a map-based overview. We also found that the motivations for selecting route presentations were influenced by user attributes such as previous experiences, a priori expectations influenced by past use, and also the novelty factor. In general, participants across the user studies were keen on the idea of using digital navigation systems within building environments. Most participants recounted occasions during the semi-structured interviews where they were lost within complex buildings and a similar system to the Hermes2 navigation system would have been useful.

Our studies demonstrated that mobile phones played a key role in providing reassurance, familiarity and comfort. For viewing route presentations, there was a strong preference for customization in comparison to public displays (e.g. as revealed in study five). This can be explained by the personal versus public nature of the mobile phone and public displays. In other words, mobile phones afford the element of ownership, whereas ownership is more distributed with public displays (e.g. shared between administrators, primary users, and secondary users). Important requirements that emerged included: tailoring the 3D route visualizations to match user walking speed, enabling users to intuitively switch between route presentations, and providing location-aware support on route presentations (e.g. through a You-Are-Here marker). An important consideration for mobile phones is that they can limit interaction and attention to the environment (e.g. the Hermes2 displays). There is a tendency to be fixated on a mobile phone, which has also been observed by Rukzio et al (2009) and Muller et al (2008) in their user studies. This behaviour can make it challenging to engage users to interact with situated displays at the same time.

Studies five and six revealed that the situated displays were useful as a resource to provide additional reassurance (to a mobile phone), an alternative means of receiving navigation assistance, and also a larger screen compared to a mobile phone screen. We found that using mobile phones as an input device to view location-aware route presentations on situated displays (through Near Field Communication technology) was a familiar technique (e.g. at the London Underground). Furthermore, we found that ideally users preferred their route presentations to be only displayed on the mobile phone. The tradeoff here is that although the displays provide a cost-effective and useful means of achieving location aware support, the style of interaction can be inconvenient to the flow of a navigation task (i.e. walking-stopping-touching a display).

Investigating the context of use for our navigation system revealed various interesting insights. An initial contextual factor that must be investigated is the impact that a navigation system might have on the building's current practices. For instance, if the Hermes2 system were to be fully deployed, the building's receptionist would take issue as it is part of a receptionist's role to direct visitors. However, the intention is to supplement existing methods of navigation assistance (e.g. printed signs) not to replace them. During the user studies, there was a sense of discomfort experienced by participants whilst using the situated displays because the owners of the displays were visible through the transparent glass surface that the displays are placed on. As the placement was designed around the messaging application, it was clear that its suitability to support navigation tasks must consider different ways of advertising their availability for navigation, or through the deployment of additional purpose-built displays on opaque surfaces, which is certainly a viable possibility given the low cost of passive NFC sensors. A number of participants anticipated privacy concerns in more sensitive environments such as hospitals where destination locations may be embarrassing if publicly viewed by shoulder surfers. A personal mobile device is ideal in such circumstances, however the medium-sized dimensions of the Hermes2 situated displays and their location in a transitional space (i.e. a corridor) can reduce visibility of their interactions and therefore has the potential of providing more private interactions.

2) To what extent can the physical and software components of the Hermes2 display deployment be adapted to assist visitor navigation and mitigate the requirement for a new digital infrastructure?

The Hermes2 display deployment was found to be useful resource for navigation in many respects. The messaging application's purpose of supporting awareness in the workplace through status messages fits in nicely with the navigation application. Determining that an office occupant is away on a conference on a kiosk display next to the building entrance would save users a potentially unnecessary trip to their office (especially in large and complex environments). The feasibility of using the displays from the perspective of its primary users (i.e. the display owners) was encouraging. However, by using the messaging application's functionality to extend the navigation application and enable further navigation related communication (e.g. messaging a display owner that a visitor is on her way) between visitors and display owners seemed less desirable for display owners (although more favourable for our study participants).

The deployment structure was such that the displays were placed a few feet from each other. This allowed the benefit of using the displays as tools for receiving location-aware navigation assistance by attaching low-cost NFC sensors. This removes the complexities of determining and calculating position through lateration and angulation, as well as further measures to handle signal propagation problems, which are required for mobile devices. This simplified approach enables a navigation system to be rapidly deployed. However, the challenges lie with the availability of these displays in areas where navigation assistance might be required. In other words, the Hermes2 displays are not placed throughout the entire building and at every decision point, thus incurring costs for additional displays. Furthermore, using the displays as a positioning tool is perhaps less fluid for users than, for instance, using positioning techniques and providing location-aware information on the mobile phone.

3) What can be learnt about the technical, as well as administrative, responsibilities and challenges of managing an existing ubiquitous display deployment that is adapted for supporting visitor navigation?

The task of managing a ubiquitous display system, such as Hermes2, involves a number of technical and social challenges. Although software issues can be dealt with relatively easily, hardware problems that involve back-end cabling and networking can be drawn-out as permission needs to be sought from the appropriate administrators. The Hermes2 deployment was designed to be a research test-bed, thus enabling flexibility for researchers to take control of its administration. A problem with this approach is that a complete transfer of knowledge was not carried out, which created the need for a learning curve. One of the key technical challenges faced over the four-year period involved handling the unwarranted compromise of the Hermes2 server, which caused it to be de-commissioned and henceforth re-configured as a virtual server. The ongoing technological shift in, for instance, touch-screen device technology was another factor. The Hermes2 displays use resistive touch-screen technology, however, most current devices are capacitive, which can cause significant impact on expectations of use (e.g. display responsiveness, feedback).

Managing the deployment also included tackling social issues, such as maintaining the satisfaction of its primary users (i.e. the display owners). As the system experienced several hardware issues over the four-year period, user confidence (i.e. by the display owners) dissipated. This was observed by overhearing conversations and through informal discussions with display owners. The drop in confidence can have a significant effect on the system as a whole, as well as for the purposes of integrating the messaging functionality into the navigation application. There is no point in exploiting status messages if the display owners are not setting them.

9.1.1 Reflections

An important limitation that affected how well the research questions were answered involved the lack of a longitudinal investigation of a fully deployed Hermes2 navigation system. Issues such as frequent hardware failures, as well as concerns raised by the receptionist, were indeed barriers to carrying out such a deployment. It can be argued that the first research question was predominantly affected by this, in that we were unable to observe users in the wild and extrapolate user preferences and requirements from such a scenario. Although it is not suggested that the design guidelines described in this thesis were erroneous, additional insights towards user preferences, behaviours, and patterns of use may not have been gained.

It is likely that carrying out a full deployment would also reveal understandings into additional long-term management challenges related to the navigation system, and therefore expand on answering the third research question. For instance, a continuous effort would be required to manage the satisfaction of users who would specifically utilize the navigation system functionality (e.g. visitors) rather than the primary messaging application. In addition, we would gain further insights into the second research question in terms of how well users in the wild are able to successfully, as well as concurrently, receive location-aware navigation support by using an existing infrastructure of situated displays, NFC tags, and Wi-Fi.

9.2 Contributions

This thesis has contributed to the domain of indoor navigation research by utilizing a user-centered approach and providing rich and qualitative insights into the design of indoor navigation systems that are tailored towards user needs. These contributions are discussed in the following sub-sections.

9.2.1 Major Contributions

1. A theoretical framework for indoor navigation system design and development. The framework involves design implications concerning user interaction preferences, requirements, motivations, and patterns of use in relation to the combined usage of personal mobile phones, situated displays and multi-dimensional route presentations. These insights are intended to aid designers of similar navigation applications to closely match user needs. The studies have shown the importance of reassurance, customizability, reliance, and the cultural characteristics of route presentations and client devices, for the design of indoor navigation systems.
2. Understandings towards the contextual implications of utilizing an existing display deployment in a complex social space for the purposes of supporting indoor navigation. The usefulness of indoor navigation systems must address the social conventions and practices that are in place within the environment. It was found that, for example, the visibility of display owners, preconceptions of display use, and user perceptions of the social norm can significantly shape user interaction.
3. Understandings into the ways in which the functionality of an existing ubiquitous display system can aid visitor navigation. Digital devices are becoming prevalent in modern buildings and there is limited understanding of how these can be adapted

for the purposes of navigation. The studies described in this thesis found that the messaging application supported by the displays were relevant and useful for navigation. The structure of the deployment also enabled a means of using the displays as positioning tools, which addresses the general complexities of calculating position and orientation on mobile devices.

9.2.2 Minor Contributions

1. Insights into the technical and social issues that emerged from the longitudinal management of a ubiquitous display system (i.e. the Hermes2 deployment). This thesis provides recommendations related to the issues with hardware management, addressing user requirements, and changes in social dynamics.
2. A novel approach towards indoor positioning through the use of situated displays and mobile phones mediated by passive Near Field Communication (NFC) technology and by using a lightweight interaction style. Past research has mainly investigated indoor positioning through the use of long range signal measurements; whereas our system utilizes a passive approach where users can be uniquely identified through the use of NFC-enabled personal mobile phones and the displays used as positioning tools.

9.3 Future Directions

The research in this thesis can be expanded and continued in several ways that would increase the external validity of our work. For instance, with more time and resources it would be beneficial to complete the development of the prototype Hermes2 navigation system and carry out a deployment in a complex and multi-level building environment in order to observe its longitudinal usage over a period of time. Carrying out a deployment would also require user performance tests in order to determine the efficiency of the navigation system (i.e. how quickly and accurately users are able to find their destination locations).

9.3.1 Increasing External Validity

The observations and analysis made in this thesis has been restricted to a single building environment, which already supports a ubiquitous display deployment. Furthermore, the nature of our user studies mainly explored a situation where users are able to leisurely find directions to a location and walk to their destination. By deploying a prototype of the Hermes2 navigation in a more commercial setting, where for instance, situated displays are not initially supported, would provide a better understanding towards the costs and efforts involved in a real-world scenario. This would involve carrying out a deployment through discussions with the building owner and by gaining an understanding of current visitor conduct, social norms, and so forth. Furthermore, by observing visitors through a longitudinal deployment, they can be observed under varying situational factors such as time constraints.

Another important area where we can expand the external validity of our research would be to test the capability of the prototype navigation system for supporting multiple users (i.e. in a busy environment). For instance, we would develop a better understanding of the server requirements and software capabilities of handling a variety of users. This also brings us to further observing social behaviors surrounding the navigation system without the constraints of a user study. For instance, would users be comfortable interacting with public kiosk displays with idle users nearby? To what extent do users require their destination locations to be kept private?

9.3.2 Accessibility

Another avenue of future work would be to include measures and functionalities that adhere to the disabilities discrimination act into the prototype system in order to cater for the needs of everyone within building environments. For example, a key consideration for supporting accessibility is enabling the navigation system to select appropriate routes (e.g. lifts vs. stairs), as well as the ability to provide directions through additional modalities (to visual) such as audio, embossed information, Braille information and audible information. It is also necessary to design route presentations and signage that conform to the disability discrimination act, by adopting guidelines from the Sign Design Guide (Barker and Fraser, 2000). The guidelines from this book have already been adapted in the practices of a commercial company with which we have had discussions of utilizing the Hermes2 navigation system in commercial building environments.

9.4 Concluding Remarks

This thesis has conducted research in the Infolab21 building on the Lancaster University campus (United Kingdom) using the prototype Hermes2 indoor navigation system. The work has involved investigations which have utilized a user-centered approach in order to determine the interaction preferences of users, requirements, patterns of use, and user motivations which are intended to aid designers of similar systems and applications that closely match user needs. In particular, we were interested in the combined use of personal mobile phones, multi-dimensional route presentations and also the existing Hermes2 system, which consists of a deployment of 40 door displays across two corridors on two building levels. The work has also investigated the navigation system's context of use and the ways in which social norms, conventions and notions such as ownership of use, can shape user interactions. Furthermore, we have reported on the insights gained from the longitudinal experiences of managing a ubiquitous display deployment such as Hermes2 and provided recommendations of the relevant responsibilities, as well as the social and technical issues that can emerge over time.

Although it is important to establish the functional feasibility of interactive systems, it is also necessary to form a rich understanding of its users and the environment in which the system is deployed. The intention of the research carried out over the past four years is to provide useful insights for navigation system designers, as well as to contribute knowledge into the domain of indoor navigation and Human Computer Interaction.

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Appendix A

Hermes2 Maintenance Logs

A.1 General Log Excerpt From 2011

(Update 7th September 2011)

Contacted ISS to examine the switch in the machine room. 4 displays were not receiving the boot filename (i.e. could not connect to the network), we checked two of the ports by connecting a laptop to check if there was connectivity (we found there wasn't). The issue was with the PASS system that ISS have introduced and those ports were not validated. They were then put on the PASS system and the displays connect to the network without any issues.

All displays on C floor are functional. Some user interface issues need to be examined. C44 display has some internal cabling issues. C45 needs some attention as the VGA cable is coming loose. All displays on C floor are also running the UBUNTU version with Google chrome web browser for the application.

(Update 23rd August 2011)

A few displays have issues with receiving the boot filename from the network: C44, C46, C56, C50. This might be an issue with the switch in the machine room. C44, C56 and C50 had to undergo floorboard removal and plugging in of a ps2 keyboard to access the BIOS and set the primary boot device to be LAN rather than CD-ROM. However, it cannot seem to reach the host and receive a boot filename to load the OS.

Today C44 floorboard was removed and a laptop was attached to the network cable. The network cable plugged into the actual SBC board was unplugged and plugged into the laptop. There is internet connection but it cannot connect to 10.22.12.4, where it gets the boot filename from. As these displays have been switched off for a long time, the switch might require a restart.

Need to contact ISS to get into the machine room for this. As a test, C44 display, C44/1 switch port cable needs to be unplugged and plugged into the laptop. Once an internet connection is received then it should work. Suggestion is to reset the switch.

Replaced display C56 and also reset the BIOS settings by pulling up the floorboard. Same boot filename issue.

Display C5 had an issue, when UBUNTU installation was carried out, that temporary files couldn't be written to a specific directory. This was fixed by changing read/write permissions on the folder.

(Update 20th July 2011)

Attempting to fix the issue with loading X.

(Update 20th July 2011)

Library display is back up and running. We pulled up the floorboard and attached a keyboard to the SBC in order to continue. The BIOS settings were reset due to accidentally flicking a switch in the display unit cabling that resets the BIOS. The issue is not with the battery it seems. Also before netboot can take place the BIOS settings need to be changed, i.e. it because reset to the initial boot device set as the harddrive, however this needs to be changed to LAN.

Corina's display: pulled up the floorboard to carry on with the Ubuntu netboot install. Display was able to netboot and left the display to install ubuntu desktop. After this was successful, the display kept switching off when attempting to load X.

(Update 6th July 2011)

Some changes made to the Hermes2 web application:

- changed background colour to get rid of gradient lines

- custom error page created that attempts to reload the owner UI on button click

- with the above in place, Cath's display has been reactivated and will be monitored. The server error only seems to happen with this display, i.e. with a shared owner UI

- if the app cannot retrieve the IP address of a display it automatically used to go to a static error page (non user friendly, hence a custom page has been made). Also changed this so that 5 more attempts are made to retrieve an IP address, with 3 second intervals

- image re-size functionality - landscape, portrait, square. This can be controlled by the web portal with three buttons representing each aspect ratio. A field has been added to the users table in the Hermes2 database 'Img_Scale_Val' which has a constant number. This number is used to determine the image width for instance, e.g. values range from 0.7, 1, 1.33 -> portrait, square, landscape

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(Update 1st July 2011)

Found Cath's display with only the background loaded and no buttons, etc. restarted firefox. Need to find out why this keeps happening

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(Update 30th June 2011)

Door display C55: a switch was accidentally set (the switch with CMOS and Reset written on two ends). On restart (SBC and Display port) the checksum error was encountered: Checksum error, defaults loaded, press F1 to continue. This requires us to pull out the floorboard in order to plug a keyboard into the SBC and press F1. We attempted to pull out the floorboard with little success. I will try again in the evening.

Cath's display C12, seemed to hang in single display owner view without any information loaded from the database. The ip was manually enetered 10.22.12.105 in the webstartup script and it seems to be OK. For some reason it must not have been pulling the IP address. I will look into this issue

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(Update 23rd June 2011)

Door display on C44 was investigated:

checksum error - meaning that the battery on the SBC needs replacing.

Also one of the black cables that controls display output is quite loose and is causing issues. Some electrical tape might be necessary to hold the two cables together, if replacement cables cannot be found. Problem is that the cable goes under the floorboard and so replacement would be the second option.

Door display C55:

Using the SBC on this display to install a version of Ubuntu - better documentation, package management etc. and also as an attempt to solve the issue with the new displays that have arrived, namely the issue with the non responsive touchscreen. The touchscreen itself is being detected and the drivers are in place, however there is no response when the user tries to interact via touch (resolved) error encountered with Hermes2 server (on reboot) to note: the DHCP was not providing the server with an IP and thus no internet connection could be established but eventually this was resolved.

(Update 7th June 2011)

C48 display has been investigated: requires keyboard input from the SBC to continue.

actions needed:

- C48, C50 and C55 require a keyboard to be connected to the SBC underneath the floorboard in order to continue with start-up

- C44 does not seem to be receiving power, cables need examining. The display however, is working OK

- Improvements for ventilation?

- Web version required on all displays for user study

(Update 3rd June 2011)

7 new displays have arrived on the **2nd of June 2011.** A plan is required for installation, i.e. which version of the Hermes2 application should run, which units require attention regarding cabling. Currently, C44, C48 and C55 and C50 require attention.

Update today: received an error message for C48 display - unable to boot. There is an issue with the SBC

DNS entries updated for the Hermes2 server (hermes2.comp.lancs.ac.uk)

A bash script was written to update all the SBCs as well

for $i in 10 43

do

echo "cp /etc/resolv.conf sbc$i/etc/"

done

(Update 24 May 2011)

No new issues with any of the working displays.

Modifications to the web-based Hermes2 application GUI have been made:

Larger keyboard view when visitors wish to leave a text-based message

Modified shared user screen due to complaints about the previous view. One shared user complained that it is difficult to know where to click as each display owner's information is spread as Name, image thumbnail, and message. Now it is designed so that all this information appears to be in one button.

(Update 13 April 2011)

Modified C51 display as I found out that when the display owner information was changed

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(Update 12 April 2011)

There has been an issue with Internet access for the hermes2 web server machine (ina009000002). This was noted by noticing the displays that are running the web-version of the Hermes2 application - HTTP error 503. Last week an e-mail was set to change DNS entries for the network connections, which was carried out appropriately. The connection was ok after changing these settings but today the old settings expired and it appeared that it was not set up properly. With help from Steve Elliot, the issue was resolved by initially attempting to fix the problem remotely but then having to go down to the machine room. We tried unplugging the cable connected to the UPS and just dealing with the normal connection. It was found that the IP settings had not been applied properly (this information was absent from the e-mail sent by ISS). After this was resolved we re-plugged the cable for the UPS (which only needs local connectivity as the UPS behaves as a messaging system which might tell the server machine to e.g. shut down in case of an issue). The connection is now working without problems. 5 displays running the application have been rebooted via putty

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(Update 7 April 2011)

Switched off display at C13 as currently no staff member in the office. The SBC and Display ports were switched off and also the Set_SBC_Status field in the sbcconfig table on the Hermes2 database has been set to 'off' so that the SBC is not polled by the CheckSBCs class (which attempts to switch on working SBCs if they are switched off, i.e. possibly crashed).

C51 has new academic staff and researchers and the display owner names have been changed. Three new users have been added and the following database tables were changed: users, hermes2ipidmappings, hermes2hidtouidcompmap, and hermes2hidtocompmap.

Display owner of the C12 shared display has request details to the hermes2 web portal (forgotten username, password) and has asked how to clear a temporary message from the display. Owner suggested that a button be placed which says "Clear message". The GUI will need modification with three buttons: (**Clear message, Clear image, Clear all)**

(Update 30 March 2011)

Performed a routine check for working/non-working displays:

Active Displays: D20, D19, D18, D17, D36, C51, C48, C43, C42, C54, C41, C40, C12, C13

Inactive Displays: D23, D29, D22, D30, D21, D31, D33, D34, D35, D37, D14, D13, D12, C46, C50, C45, C44, C51, C55, C56, C57, C58

D16 was found to be switched off, however the display appears to be switched on and the SBC working from checking the midspan. Needs investigation

--- ***(Update 30 March 2011)***

Note: when compiling JAVA code on the Hermes2 server (e.g. through Putty) for CheckSBCs.java, the following code is necessary (with the .jar files defined in the classpath):

javac -cp ./:./activation.jar:./jdbc-mysql.jar:./mail.jar CheckSBCs.java

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(Update 30 March 2011)

I have been added to the **h2feedback** mailing list last week and now able to reveive e-mails based on failed power cycles for unreachable (i.e. crashed) SBC computers. Offices with SBC issues include C44, C56, C50, C56, D34, D35 and C55. On the Hermes2 server, a script runs a JAVA class called **CheckSBCs** which checks for crashed displays and then attempts a reboot 3 times. If more than 3 times, the value is set to 99 and an e-mail is sent to the members of the h2feedback mailing list, stating that a reboot has been attempted 3 times. However, since we know which SBCs are inactive, this is not necessary. Also displays that have been switched off do not require this polling feature.

Solution: an additional column (Set_SBC_Status) has been added to the **sbcconfig** table in the Hermes2 database which takes in two values: '0' if the display unit is desired to be set to disabled, and '1' if set to enabled. By doing this, the CheckSBCs.java class now only polls the units that are set to 1. This way, the ones that are already known to be faulty do not go through reboot attempts and if any more SBC units become faulty it will be known. This has also solved the issue of keeping an SBC switched on which has a switched off display (due to melted VGA chips). Although in the **crontab** script, the 'PortOn' and 'PortOff' commands have been commented out (i.e. no longer executed) the CheckSBCs class will power them on in any case. Therefore switched off displays with working SBCs also now have been disabled for polling in the sbcconfig table. These include C57, C53, C55, D39, D14, C45, D33, D31, D21.

(Update 22 March 2011)

Two 'faulty' displays were tested, which had been out of use. They were labelled faulty in terms of the touchscreen on the edges (i.e. problems with calibration). These were tested on the C48 set-up (sbc27) and no issues were found. Now there are two working displays

----

(Update 09 March 2011)

Modifications to the Hermes2 web application graphical user interface:

(The appearance of buttons has been changed and follows a similar design to Google's Android operating system)

Button appearance has been changed

The keyboard has been re-implemented (no tables used anymore in .NET code, and better navigation for CAPS and symbols)

Temporary images are now supported

Issues still to address:

Keyboard buttons need to be slightly larger

Performance still remains inadequate (the cause of this could mainly be down to its web implementation)

Temporary message list needs to be re-implemented, i.e. the drop down effect needs to be removed as it hinders performance

Exiting the keyboard or scribble messaging options requires a prompt

A possible distinction needs to be created between the owner options and visitor options (perhaps with a titled border around the buttons for owner and visitor)

Note on rebooting firefox on gentoo:

export DISPLAY=:0.0

pkill firefox

./webstartup

(Update 09 March 2011)

Discussion of possibilities for powering up the displays with burnt out VGA chips in composite mode:

Hi Faisal

We looked at using a VGA to composite cable but the VGA connector on the motherboard has to be wired a certain way for this to work. When we purchased one it didn't seem to work with the SBC suggesting the boards aren't wired correctly for its use. The SBC also has header pins for composite out but the problem is finding them as we don't have a manual, the one we found was for an older board from the original prototype.

Even if we did get composite-out working on one of the spare SBCs we have in the office it's only the first step. To get it working on the installed displays we'd have to:
1) Take the display unit off the wall, take it down to the hardware lab and attempt to solder wires onto the remaining stubs of the composite-in cable on the display (they've been trimmed off presumably to save space). This could be very tricky as very little wire has been left, so there's no room for accidentally cutting the wire when stripping it and it's very thin wire, think headphone wire! Though we do have the advantage of numbers i.e. we have lots of displays.
2) The other end of this wire will be connected to the multi-pin connector which attaches to the cable in the door frame. Assuming that there are two spare pins and that all pins were connected to the corresponding pin on the other end i.e. they didn't just connect the pins they needed. If these assumptions are false we'd have to run another cable down the door frame and potentially need to solder connectors onto the wire in the corridor which would likely require lots of paper work to be filled out i.e. risk assessment, method statement, hot works permit (I think soldering is classed as welding) etc. What was required when they put the original cables in, thinking about it did they use crimp connectors to get round the soldering issue?
3) Lift up the floor, removed the SBC and take it to the hardware lab, solder wires between the composite out connector and the multi-pin connector, test it and replace it. Are we allowed to pull up the floor at random or do we need to get somebodies permission?

--Matt

(Update 10 February 2011)

D19 and D20 are up again.

Actions:

Contacted ISS and re-visited A29 machine room. Switched the connection ports for D19 and D20 with those that were attempting to power switched off displays.

Switching:

D19 Adrian Friday - 10.22.12.66 (sbc) 1 (display) 2 SWITCHED WITH D12 Chris Paice - 10.22.12.64 (sbc) 7 (display) 8

D20 Nigel Davies - 10.22.12.66 (sbc) 3 (display) 4 SWITCHED WITH D13 Andreas Mauthe - 10.22.12.64 (sbc) 9 (display) 10

Updated Hermes2 Database tables, i.e. the sbconfig table - updated PoE IP addresses, etc.

(Update 07 February 2011)

D19 and D20 are down again, with the same error. It might be useful to attach them to a different midspan, e.g. one that might be powering displays that are currently switched off due to burnt out VGA chips

Will need to note down possible connection ports and then e-mail ISS again.

(Update 02 February 2011)

Data feed is back on for displays D19 and D20. I arranged an inspection of the data switches, etc. in A29 and all it needed was a power cycle reboot.

(Update 24 January 2011)

It appears that the midspan 66 (IP 10.22.12.66) is currently down. Thus, displays D19 and D20 are not booting up and seem to be hanging on an error "Network unreachable". It is odd as they seem to have power, but no boot image. The error might have shown up as the displays were attempting to shut down. So, I need to get in contact with ISS (Ian Anderson) in order to get into the ISS Machine Room where all of the Hermes2 equipment is stored to inspect the midspans.

When attempting to inspect the midspans through the web-portal, IP 10.22.12.66 was not accessible. The portal allows control of the display power and also power to the SBC port. To set this up I had to do the following:

I already had Putty

Download Xming http://mirror.cse.unsw.edu.au/pub/xming/ to access the web portal via the Hermes2 server machine (allows a graphical user interface to be rendered)

Set up putty according to instructions provided in http://www.cse.unsw.edu.au/~helpdesk/documentation/Putty.html. Basically on the settings on the left hand side, select X11 under SHH and enable X11 forwarding. Then in Session, save and initialize connection to the Hermes2 server

After logging in, by typing firefox, it brings up the firefox browser in Xming, and then the web portal can be accessed to control the midspans

----

(Update 24 January 2011)

Active displays: C12, C13, C40, C41, C42, C43, C48, C51, C54, D16, D18, (D19 and D20 have a connection error), D36

Inactive displays: D23, D29, D22, D30, D21, D31, D33, D34, D35, D37, D14, D13, D12, C46, C50, C45, C44, C51, C55, C56, C57, C58, D17

A.2 Hermes2 Virtualization Logs

Meeting tomorrow about the Hermes2 virtual server set-up.

Issues to consider
- the VM has to be on the VLAN
- 2 network ports necessary, one for the display network (i.e. where the Hermes2 dispays run on) and one for the LANCS network (otherwise there cannot be any outside access to the server)
- need to set up the DHCP server on the VM for the display network. The config file for this is currently on the hermes2 backup drive. This is a text file. /etc/dhcp3/dhcp.conf. This will probably need to be re-written rather than copied. The config file maps MAC addresses to the IP address, had the netboot stuff, i.e. what files to load when the displays boot up.
- TFTP settings – the first thing that the displays need to do when they boot
- NFS share – indvidual display boot information.
- grub file
- MySQL database needs to be set up. Probably on the windows machine.
- IP tables to move traffic between LANCS network to the display network
- DNS settings
- POE switches

February 6, 2012 at 12:07

Meeting today with Keith, Peter Hurley and Steve Elliott.
Steps to be taken:

1. Request for a second network port (Pete and Steve will email Matt re this)
2. Accounts with sudo access will be set up
3. I need to compose a list of packages that are necessary: Apache, MySQL, TFTP, NFS, DHCP
4. Mail forwarding considerations (e.g. if display owners want to set a message via email)
5. I need to e-mail Matt about how the VM can be set up with the VLAN

February 7, 2012 at 14:20

Sent the network configuration file to Steve, and also provided a list of packages that need to go on the server. Version numbers need to be considered in case there are any issues with dependencies

February 9, 2012 at 15:27

Friday 28th May 2012 –
ISS have emailed back and have configured the hermes2 server so that the displays can boot from the core network, i.e. the DHCP server. Each display box (and thus mac address) has been assigned a specific IP.address. The route point has also been established.

The POE switches each have an IP address as well so we managed to log into that (and of course, change the security so you have to log in. The log-in seemed to work and we picked C42 display to test. Using the POE switch interface on the web browser, we restarted C42 and it seemed to work.

The next step was to transfer over the disk image from the old hermes2 server to the new one (i.e. from the backup on the disk drive), put it in the correct directories and edit the pxelinux configuration, i.e. add a file with a display's mac address, which has information about what to boot. The NFS server also has to have its exports file modified to allow access to these displays.

May 28, 2012 at 14:51

Updates on the hermes2 server:

MySQL:
MySQL server configured and allows remote connections. PhpMyAdmin installed as well to allow browser access to the hermes database. The old mysql dump file was used (hermes.sql) in order to restore the database. All the IP addresses in the database need to be modified to the new addresses (i.e. the 10.23.65.xxx)

Web Portal:
The files from the web portal on the old hermes server were transferred across. The server name, username/password needed to be changed. Also need to develop a script that will restart the web application / the display.

FTP:
vsftpd FTP server has been installed so that, for example, the web portal php files can be edited, etc. Some priveleges need editing for the www/ directory

Booting displays:
Added in the relevant java files that turn on/off the displays. Edited the code so that authentication is now used for accessing the port configuration. Next step is to edit the crontab file so that the displays are scheduled to switch on.

NEXT TASK: look at the web application, make any possible changes and plan the user study

June 8, 2012 at 11:54

Quick note about the location of the web-application startup file for each sbc :

location: /srv/disks/SBC10/home/sbc/.xinitrc

content:
#!/bin/bash

ip=$(ifconfig eth0 | grep 'inet addr' | awk '{print $2}' | sed 's/addr://')

/opt/google/chrome/google-chrome –
app=http://ina009000002.lancs.ac.uk/hermes2ajax/?ip=$ip

#/opt/google/chrome/google-chrome –app=http://www.weareinstrument.com/countdown/

June 11, 2012 at 11:14

Needs doing re hermes

1. Ability to send emails to display owners when a new message is set using the displays (need to check whether a mail server has been set up)
2. Scribble and text/keyboard message files need to be stored on the hermes server – need to edit priveleges and make sure all the variables have the correct directory names etc.
3. Web portal requires the ability to restart the display application and/or the display itself. Need to make bash scripts for this..
4. If display owners are going to use their displays again, they will need password reminders, etc. Also changes in the office staff need to go into the database

5. Database IP addresses need changing to reflect changes
6. Database needs updating everytime a new message is set or removed on the display
7. Display monitoring – for crashes or non-booted displays
8. Crontab entries for booting displays on a fixed schedule

June 12, 2012 at 18:16

To ssh into the display SBCs (if they're on), need to type:
$ ssh -l sbc 10.23.65.XXX or $ ssh sbc@10.23.XX.XXX

Normally, if chrome needs to be restarted due to changes to the app, then type: "killall chrome && sleep 1 && rm -rf .cache/google-chrome"

For security reasons, there needs to be a password verification (except for the hermes server, which would need the key to login automatically for crontab puposes)

To get to the PoEControl port on and off java files: $ cd /usr/local/PoEControl/ java PortOn 10.23.X.XXX Y Z

Hermes2 application:
Usability problems need addressing. It seems that the session variables of the ip address etc. seem to reset every now and then, so I've made it so that they are cached instead. Also it would be a better solution to, rather than redirects to Default.aspx, redirect to Default.aspx?ip=10.23.65.XXX

the non-responsiveness of the buttons have been solved with adding 'onmousedown' rather than 'onclick' which is both a mousedown and mouseup event

June 15, 2012 at 15:07

Changes to web application:

Some of the changes needed to improve the responsiveness of the GUI required data to be sent to the server, whilst some can be handled simply via javascript. One of these includes being able to set a temporary message.

List of button clicks/events that require improved response:

1. Scribble button -done
1.1 Send button -done
1.2 Exit button -done

2. Send text message button -done
2.1 Keyboard buttons -done

2.2 Send button -done
2.3 Exit button -done

3. Owner options button – done
3.1 Scroll up button – redesigned
3.2 Scroll down button – redesigned
3.3 Temporary messages button -done

4. Back to visitor options button – done

5. Remove temporary image -done

6. Remove temporary message -done

June 20, 2012 at 16:38

Left to do on the hermes2 app:
- On scribble and keyboard messaging exit – rather than refresh, hide panels etc. for smoother transition
- Optimise scribble, too slow at the moment – unusable
- Shift keyboard panel down slightly
- Temporary message buttons – increase size and add padding
- New temporary message set (design feedback) and also attach timestamp

June 25, 2012 at 15:40

Setting up a display with the new configurations:

1. Go to the /srv/disks/ directory and then cp -a clean SBCxx to create a new sbc directory
2. Go to the /srv/tftp/tftpboot/pxelinux.cfg/ directory and create a new file with the new mac address
3. Go to the /etc/ directory and edit the exports file by adding a new entry for the new display at the bottom
4. restart the nfs server from the root directory / sudo /etc/init.d/nfs-kernel-server restart

August 2, 2012 at 16:35

Found the issue regarding the boot process of the hermes displays. When it asks the DHCP server for an ip address the second time (when the NFS is about to load) the DHCP somtimes doesn’t send a response and the display times out after 60 secs.

So in the pxeconfig folder, the files (named with relevant MAC addresses) need to be edited:
(example for keith's display)
APPEND root= initrd= netboot=nfs nfsroot=10.xx.xx.xx:/srv/—-/xxxxx
ip=10.xx.xx.xxx::GATEWAY:255.255.255.0::eth0:off rw

This must be repeated for other displays when they will be switched on

Appendix B

User Study One

B.1 Participant Information Document

Participant Information Document

Infolab21 Navigation System

Dear Participant,

You are being invited to participate in a user study, which involves using a Navigation System that helps you find your way inside a building. The Navigation System is a computer program that you will be able to access on a touch-screen display inside the Infolab21 building in Lancaster University. Please take some time to read through the next few sections of this document to understand **why** the study is being conducted and **what** the study will involve.

- **Part 1** of this document explains the purpose of this study and information about your participation
- **Part 2** of this document explains what the study will involve

If there are any uncertainties or questions, please contact me:

Faisal Taher

Email: f.taher@lancaster.ac.uk

Mobile : 07854314890

Part 1

What is the purpose of this study?
Imagine that you are inside an unfamiliar building and you are trying to reach a certain location (e.g. an office) but you are not sure which way to go or how to get there. You may ask someone, try and look for a map, etc. The purpose of this study stems from this navigational issue and introduces a system (a computer program) that aims to help people find their way in unfamiliar locations. It explores the concept of integrating both the 2-dimensional and 3-dimensional aspect in navigation, as well as allowing such information to be mobile.

Why have I been chosen?
At least 6 participants are required for this study.

Do I have to take part?
No. Your participation is strictly voluntary and you may therefore choose to withdraw from this study if you wish.

Expenses and payments
You will be provided with refreshments, but unfortunately no monetary reward is available.

Will my participation be kept confidential?
Yes. Any information gathered in this study, including your identity, photographs and recordings will be kept strictly confidential. All data gathered from participants will be regarded as anonymous in any reports that result from the study.

Part 2

What will the study involve?
You will be asked to use the Navigation System to receive directions to a given location, while at the same time **thinking out loud** as you are using the system. This information will be recorded with a Dictaphone and will be kept strictly confidential. Please note that you may object to any part of this if you wish to do so. Following this you will physically find your way (or walk) to the destination. You will then be asked a few questions about your experiences in using the system, followed by a short questionnaire.

Problems and complaints

If you have any problems or complaints about this study, please let me know. This also applies for any problems during the course of the study. If you wish to complain formally, please contact the project supervisor Dr. Keith Cheverst (kcheverst@gmail.com).

What will happen to the results of the study

All of the data collected from the study will be analyzed and used for a report. You will not be identified in any report or publication unless you have given consent. All information gathered will also be kept genuine and accurate.

Thank you for your interest and time

Have a nice day! ☺

B.2 Tasks and Questionnaire

Introduction

Before you begin, please imagine the following scenario:

You are a first year undergraduate student in Computing and you are having some trouble connecting to a network drive that contains some resources that you need for your coursework. You decide to go and have a chat with **Steve Elliot**, office number **C50** in the **Computing Department**. Steve is the **administrator** of the Computing network.

A Quick Reminder:

Contact: **Steve Elliot (C50) Network Administrator, Computing Department, Infolab21**

Part 1 – Tasks

Please carry out the following tasks:

1. Please interact with the navigation system for directions to Steve's office.

2. Please walk to the office

3. Once you have found his office, please find your way out.

Part 2 – Interview

Thank you. You will now be interviewed with a few questions about your experiences.

Part 3 – Questionnaire

Some key terminology (key-words) to remember:

- **System** – the computer program that you have used to find your way to different locations.
- **3D Route Preview –** the 3-dimensional (3D) video clip that shows you how to get to a location.
- **Map** – the 2-dimensional (2D) map

Please tick the appropriate box for each question. Comments are optional.

1. Have you had any previous experience with 3D environments? (E.g. virtual tour programs, computer games, etc.)

☐ Yes
☐ No

If yes, please state type of experiences:

____

____

2. Please give yourself a rating of expertise for reading regular maps?

☐ Expert (excellent at reading maps)
☐ Average (generally good at reading maps)
☐ Novice (generally confused when reading maps)
☐ Never used a map
☐ Other _____________

Comments:

____

____

3. To find my way inside Infolab21, I used the following:

☐ Map
☐ 3D Route Preview
☐ Both

Comments:

____

____

4. I would generally feel more **comfortable** using the following:

☐ Map
☐ 3D Route Preview
☐ Both
☐ Neither

Comments:

____

____

5. In the future, I would prefer to use the following

☐ Map
☐ 3D Route Preview
☐ Both
☐ Neither

Comments:

____

____

6. I used a mobile device to download:

☐ Map
☐ 3D Route Preview
☐ Both
☐ Neither

Please give reasons for your answer:

____

____

7. I used the **Help** feature in the system

☐ Yes
☐ No

Comments:

Where applicable, please circle/tick your choice for each question and add any comments that you may have:

The system helped me find my location(s)				
1. Strongly Disagree	2. Disagree	3. No Firm Opinion	4. Agree	5. Strongly Agree
Comments:				

The 3D Route Preview (if used) allowed me to understand the surrounding environment and recognize objects and areas				
1. Strongly Disagree	2. Disagree	3. No Firm Opinion	4. Agree	5. Strongly Agree
Comments:				

The level of detail in the 3D Route Preview was about right				
1. Strongly Disagree	2. Disagree	3. No Firm Opinion	4. Agree	5. Strongly Agree
Comments:				

The length of the 3D Route Preview was about right (not too long or too short)				
1. Strongly Disagree	2. Disagree	3. No Firm Opinion	4. Agree	5. Strongly Agree
Comments:				

The map was easy to read and it provided an overall understanding of the environment				
1. Strongly Disagree	2. Disagree	3. No Firm Opinion	4. Agree	5. Strongly Agree
Comments:				

The amount of information displayed on the map was about right				
1. Strongly Disagree	2. Disagree	3. No Firm Opinion	4. Agree	5. Strongly Agree
Comments:				

I was able to easily find my way back				
1. Strongly Disagree	2. Disagree	3. No Firm Opinion	4. Agree	5. Strongly Agree
Comments:				

I found it easy to download the map or/and the preview to a mobile device				
1. Strongly Disagree	2. Disagree	3. No Firm Opinion	4. Agree	5. Strongly Agree
Comments: ____________ ____________				

It was helpful to download the map or/and the preview to a mobile device				
1. Strongly Disagree	2. Disagree	3. No Firm Opinion	4. Agree	5. Strongly Agree
Comments: ____________ ____________				

The Help feature in the system was helpful				
1. Strongly Disagree	2. Disagree	3. No Firm Opinion	4. Agree	5. Strongly Agree
Comments: ____________ ____________				

The system would be useful in other on-campus departments or other buildings				
1. Strongly Disagree	2. Disagree	3. No Firm Opinion	4. Agree	5. Strongly Agree
Comments: ____________ ____________				

Additional Comments

____

Appendix C

User Study Two: Questionnaire

C.1 Example of a Questionnaire for Display Owners

Exploring Mobile Phone and Situated Display Support for Indoor Navigation

A Brief Introduction

Our motivation is to explore digital and location-aware support for visitors to the Infolab21 building using technology such as mobile phones and situated displays. In this case we are exploring how users can benefit by viewing a virtual walkthrough and a digital 2D map of the environment. By using a system prototype (in an exploratory user study) installed in the Reception area on B-floor, users will be able to view and "take-away" or download the navigational information to a mobile phone and furthermore, the Hermes2 situated displays will provide complementary wayfinding support by displaying indexical navigational cues, e.g. graphical arrows pointing users to the direction of their destination. To put this into context, we can examine the following scenario:

"Jane, a first year undergraduate in Computing, enters the Infolab21 building for the first time in order to meet her course tutor. She knows the name and office number of her tutor but she is not sure how to find her way to his office. Jane approaches the reception desk but finds that nobody is there. She then notices a flat screen display placed on the desk showing a user interface that can be used to receive directions to her tutor's office. Jane interacts with the interface and on the screen showing a list of staff members, she notices a message under her tutor's photo saying that he is currently in his office. She then decides to view a 3D route to her tutor's office and because she feels that the route may be difficult to remember, she takes out her mobile phone and downloads the 3D route by using Bluetooth. She had also requested for navigation arrows to be shown along her route on the situated displays (although she is not entirely sure what this means). Jane walks along using her mobile phone showing the 3D route to help guide her and on the way she comes across the situated displays showing graphical arrows. She feels further reassured that she is going in the right direction and proceeds to successfully find her tutor."

Note: The prototype system described is only for the purposes of research at this stage, with no intention of deployment.

The figure below shows the user interface of the system prototype displaying a list of staff members:

The photographs used are from the departmental website

Below is an example of what a navigation arrow would look like on a Hermes2 display:

The arrow on the display would only appear for a short period of time, after which the display will resume showing the hermes2 interface.

Questionnaire

Please circle or tick your choice for each question and add any comments that you may have

I use my Hermes2 display to set a temporary message:

1. Every day
2. Every few days
3. Once a month
4. Never
5. Other ___________________________________

Comments:

I would be comfortable knowing that visitors to the Infolab21 building can view directions to my office (as a 3D route or on a digital 2D map)

1. Strongly Agree
2. Agree
3. Undecided
4. Disagree
5. Strongly Disagree

Comments:

I would be comfortable knowing that visitors to the Infolab21 building can view the temporary message set on my Hermes2 display on the system prototype in the Reception

1. Strongly Agree
2. Agree
3. Undecided
4. Disagree
5. Strongly Disagree

Comments:

I would be comfortable with having my photograph displayed on the 'staff member list' on the user interface of the system prototype (see page 2)

1. Strongly Agree
2. Agree

3. Undecided
4. Disagree
5. Strongly Disagree

Comments:

I would prefer to choose when visitors to the Infolab21 building can view my Hermes2 temporary message and when they cannot (on the system prototype in the Reception)

1. Strongly Agree
2. Agree
3. Undecided
4. Disagree
5. Strongly Disagree

Comments:

I would be comfortable with allowing graphical arrows to be shown on my Hermes2 display to provide navigational support for visitors (see page 2)

1. Strongly Agree
2. Agree
3. Undecided
4. Disagree
5. Strongly Disagree

Comments:

It would be helpful if a message was sent to my mobile phone when a visitor is on his/her way to my office, after he/she has used the system prototype

1. **Strongly Agree**
2. Agree
3. Undecided
4. Disagree
5. Strongly Disagree

Comments:

If I am not in my office, it would be useful to establish communication with a visitor via mobile phone to arrange a time and place to meet. A visitor would send a message by using the system prototype with his/her name and number, and you would choose whether or not to pursue further communication.

1. Strongly Agree
2. Agree
3. Undecided
4. Disagree
5. Strongly Disagree

Comments:

Common across major social network services is the ability for a user to publish status updates on their profile, allowing 'friends' to follow what activities they are currently engaged in.

How often do you publish status updates within a social networking service (e.g. Facebook, Twitter, MySpace)

1. Never
2. Once Monthly
3. Once Weekly
4. Once Daily
5. More Than Once a Day

Comments:

As a display owner how likely would you be to publish status updates displayed on the hermes2 system?

1. Never
2. Once Monthly
3. Once Weekly
4. Once Daily
5. More Than Once a Day

Comments:.

As a member of infolab21 how interested would you be in seeing colleagues' status updates:

- On the door displays?

    1. Very Interested
    2. Interested
    3. Neither Interested Nor Uninterested
    4. Uninterested
    5. Very Uninterested

- On the foyer display?

    1. Very Interested
    2. Interested
    3. Neither Interested Nor Uninterested
    4. Uninterested
    5. Very Uninterested

Comments:

If you currently hold an active social networking profile (i.e. Twitter, Facebook) how useful would it be to you if the hermes2 system was able to display your social networking status updates?

1. Very Useful
2. Useful
3. Neither Useful Nor Useless
4. Useless
5. Very Useless

Comments:

Additional Comments:

Thank you for your time

Have a nice day ☺

Appendix D

User Study Three

D.1 Participant Information Document

Participant Information Document

Infolab21 Navigation System

Dear Participant,

You are being invited to participate in a user study, which involves using a Navigation System that helps you find your way inside a building. The Navigation System is a computer program that you will be able to access on a touch-screen display inside the Infolab21 building in Lancaster University. Please take some time to read through the next few sections of this document to understand **why** the study is being conducted and **what** the study will involve.

- **Part 1** of this document explains the purpose of this study and information about your participation
- **Part 2** of this document explains what the study will involve

If there are any uncertainties or questions, please contact me:

Faisal Taher

Email: f.taher@lancaster.ac.uk

Mobile : 07854314890

Part 1

What is the purpose of this study?
Imagine that you are inside an unfamiliar building and you are trying to reach a certain location (e.g. an office) but you are not sure which way to go or how to get there. You may ask someone, try and look for a map, etc. The purpose of this study stems from this navigational issue and introduces a system (a computer program) that aims to help people find their way in unfamiliar locations. It explores the concept of integrating both the 2-dimensional and 3-dimensional aspect in navigation, as well as allowing such information to be mobile.

Why have I been chosen?
At least 10 participants are required for this study.

Do I have to take part?
No. Your participation is strictly voluntary and you may therefore choose to withdraw from this study if you wish.

Expenses and payments
You will be provided with refreshments, but unfortunately no monetary reward is available.

Will my participation be kept confidential?
Yes. Any information gathered in this study, including your identity, photographs and recordings will be kept strictly confidential. All data gathered from participants will be regarded as anonymous in any reports that result from the study.

Part 2

What will the study involve?
You will be asked to use the Navigation System to receive directions to a given location, while at the same time **thinking out loud** as you are using the system. This information will be recorded with a Dictaphone and will be kept strictly confidential. Please note that you may object to any part of this if you wish to do so. Following this you will physically find your way (or walk) to the destination. You will then be asked a few questions about your experiences in using the system, followed by a short questionnaire.

Problems and complaints
If you have any problems or complaints about this study, please let me know. This also applies for any problems during the course of the study. If you wish to complain formally, please contact the project supervisor Dr. Keith Cheverst (kcheverst@gmail.com).

What will happen to the results of the study
All of the data collected from the study will be analyzed and used for a report. You will not be identified in any report or publication unless you have given consent. All information gathered will also be kept genuine and accurate.

Thank you for your interest and time
Have a nice day! ☺

D.2 Tasks and Questionnaire

InfoLab21

Exploring Mobile Phone and Situated Display Support for Indoor Navigation

Tasks and Questionnaire

Please imagine the following scenario

You are a first year undergraduate student at Lancaster University doing a Computer Science degree. You are having difficulty with one of your modules and you decide to go see the module lecturer inside the Infolab21 building.

Lecturer name: Dr. Keith Cheverst

Office number: C42

Your task: Please use the interface to receive directions to Keith's office and then walk to his office. You are welcome to download navigational information (the map or the 3D route) of your choice from the interface using the mobile phone supplied to you.

Questionnaire

Please circle/tick appropriately and add any comments that you may have

How experienced are you with technology?

1. Expert
2. Above Average
3. Average level of expertise
4. Some knowledge
5. Not really experienced

Comments:
____
____
____

Please give yourself a rating in terms of how well you can generally read maps:

1. I am excellent at reading maps
2. I am about average at reading maps
3. I am generally confused with reading maps
4. I am unable to read maps
5. It depends on the map

Comments:
____
____
____

In the future, I would use the following type(s) of navigational information to receive directions:

- ☐ 3D route
- ☐ Map
- ☐ Both

Comments:
____
____
____

In the future, to help guide me along a route I would use the following:

- ☐ Mobile device
- ☐ Situated displays showing navigation arrows
- ☐ Both

Comments:

____
____
____

(If used) The map had sufficient detail and was easy to understand

1. Strongly Agree
2. Agree
3. Undecided
4. Disagree
5. Strongly Disagree

Comments

____
____
____

(If used) The 3D route had sufficient detail and allowed me to form a sense of familiarity with the environment

1. Strongly Agree
2. Agree
3. Undecided
4. Disagree
5. Strongly Disagree

Comments

____
____
____

I found it useful and reassuring to use a mobile phone to help guide me to my destination

6. Strongly Agree
7. Agree
8. Undecided
9. Disagree
10. Strongly Disagree

Comments

____

____

____

I found the navigation arrows on the situated displays helpful and reassuring in guiding me to my destination

1. Strongly Agree
2. Agree
3. Undecided
4. Disagree
5. Strongly Disagree

Comments

____

____

____

I found it useful to view the staff member's message under his/her photograph

1. Strongly Agree
2. Agree
3. Undecided
4. Disagree
5. Strongly Disagree

Comments

____

____

____

I would find it useful to send a message to a staff member to his/her mobile phone by using the system user interface in case he/she is not currently in the office.

1. Strongly Agree
2. Agree
3. Undecided
4. Disagree
5. Strongly Disagree

Comments

____

____

____

I would feel comfortable if the situated displays are able to 'track' me while I am walking to a destination. For example the displays would communicate with your mobile phone by using Bluetooth.

1. Strongly Agree
2. Agree
3. Undecided
4. Disagree
5. Strongly Disagree

Comments

____

____

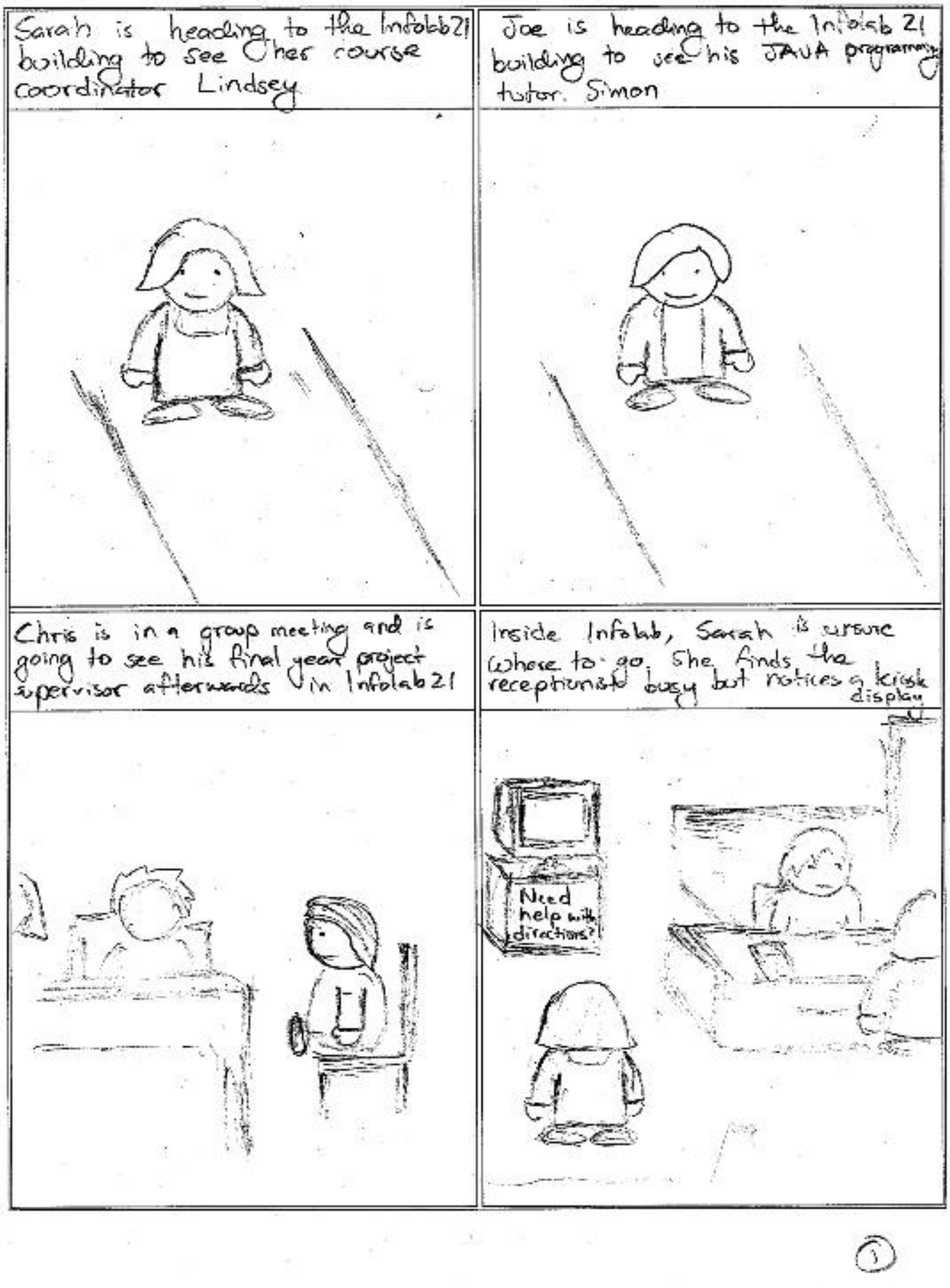
____

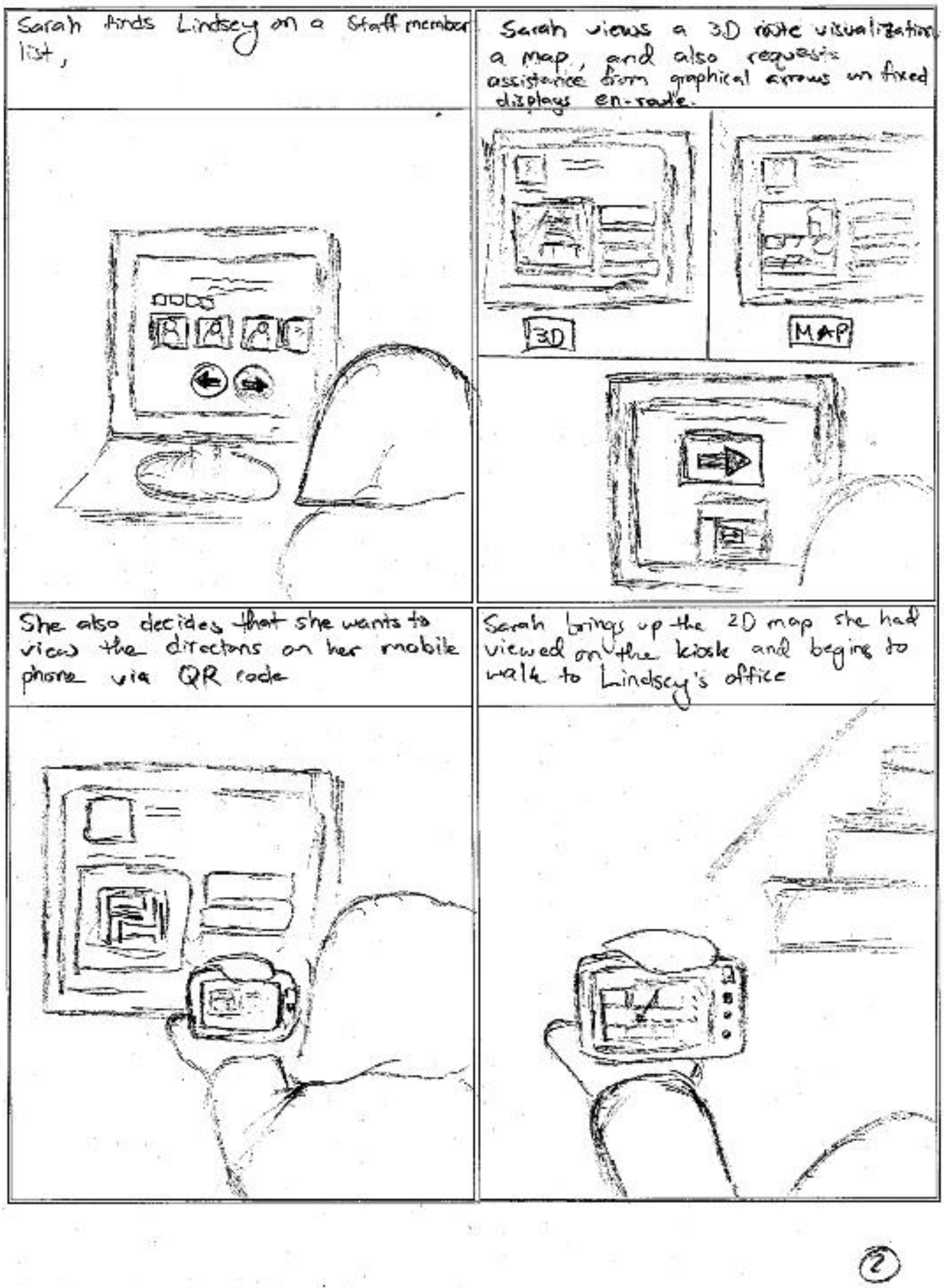
Appendix E

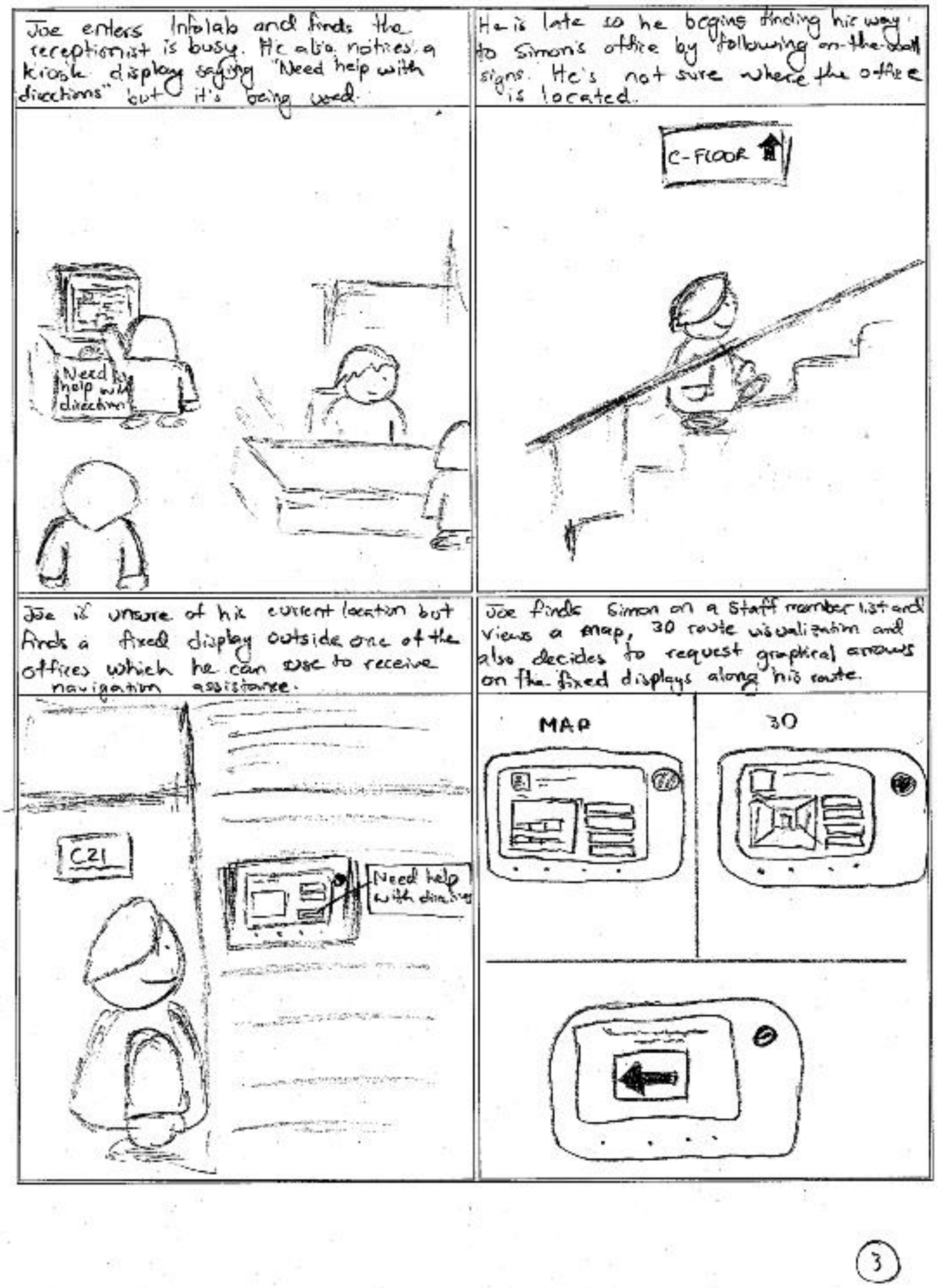
User Study Five

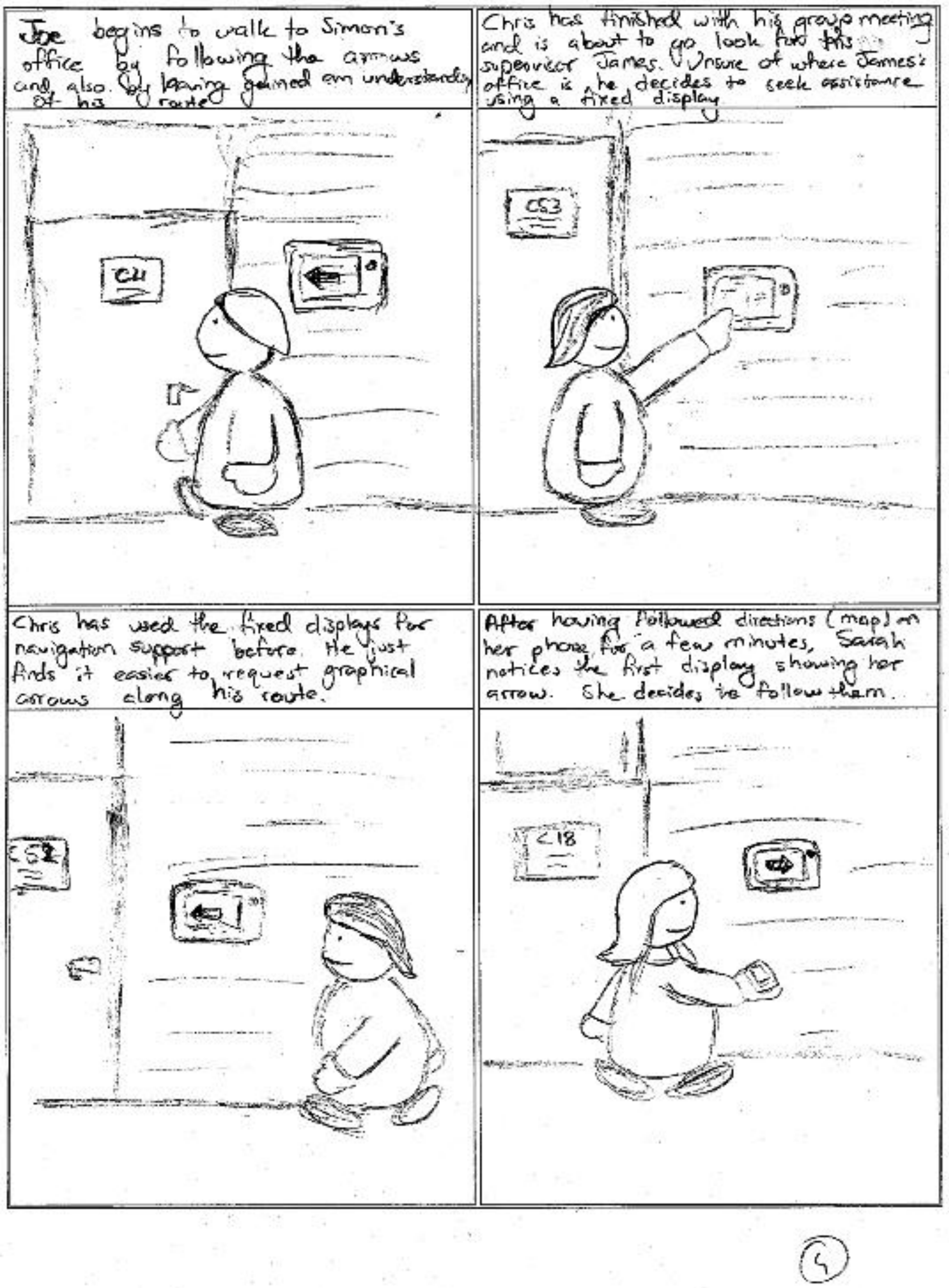
E.1 Storyboards

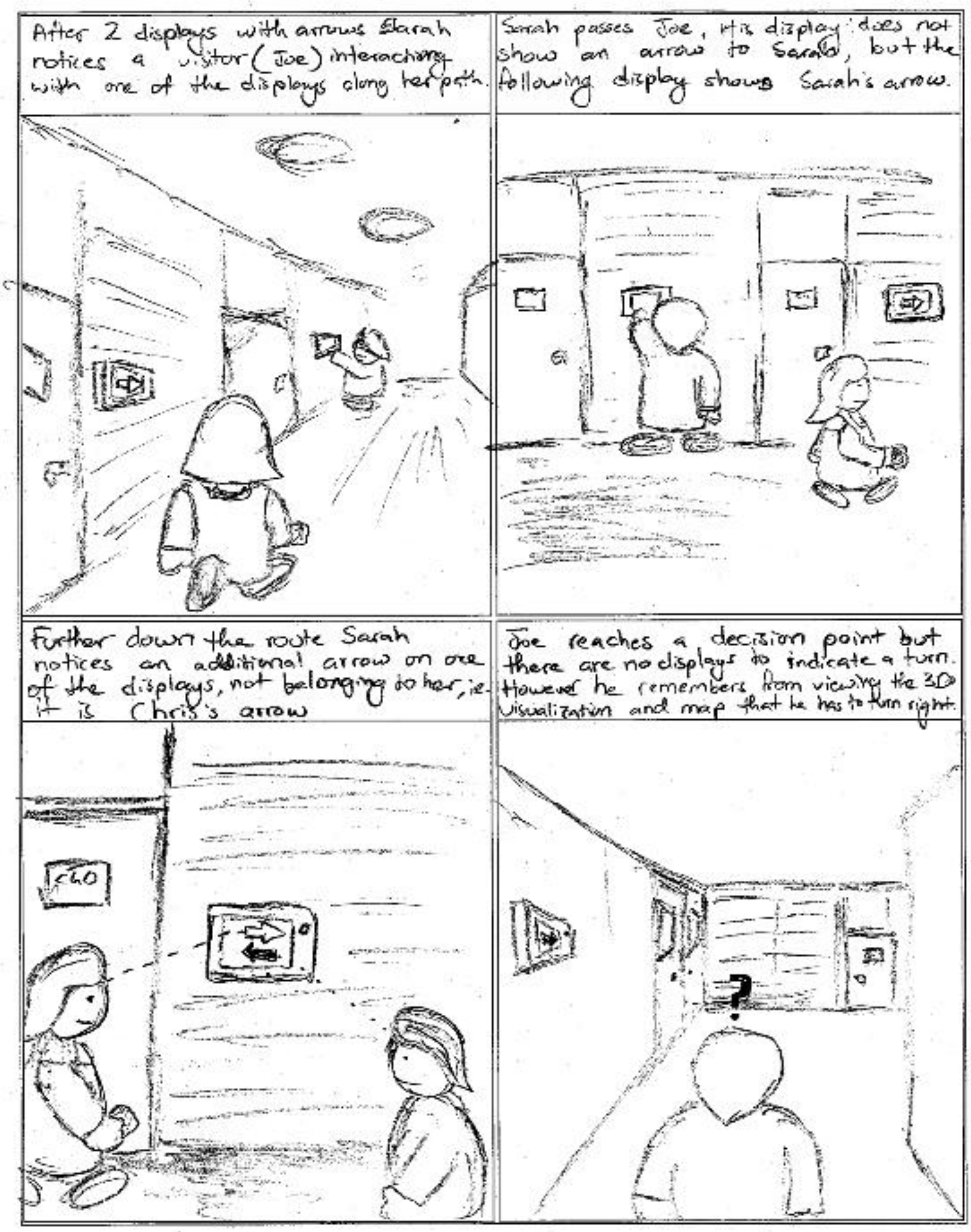
The following storyboard was designed to inform the process of the study and the set-up of the prototype Hermes2 navigation system. We also explored the potential of how multiple users could be supported by the displays. However, this was not adapted for the user study.


Sarah is heading to the Infolab21 building to see her course coordinator Lindsey
Joe is heading to the Infolab 21 building to see his JAVA programming tutor. Simon
Chris is in a group meeting and is going to see his final year project supervisor afterwards in Infolab21
Inside Infolab, Sarah is unsure where to go. She finds the receptionist busy but notices a kiosk display
Need help with directions?
1

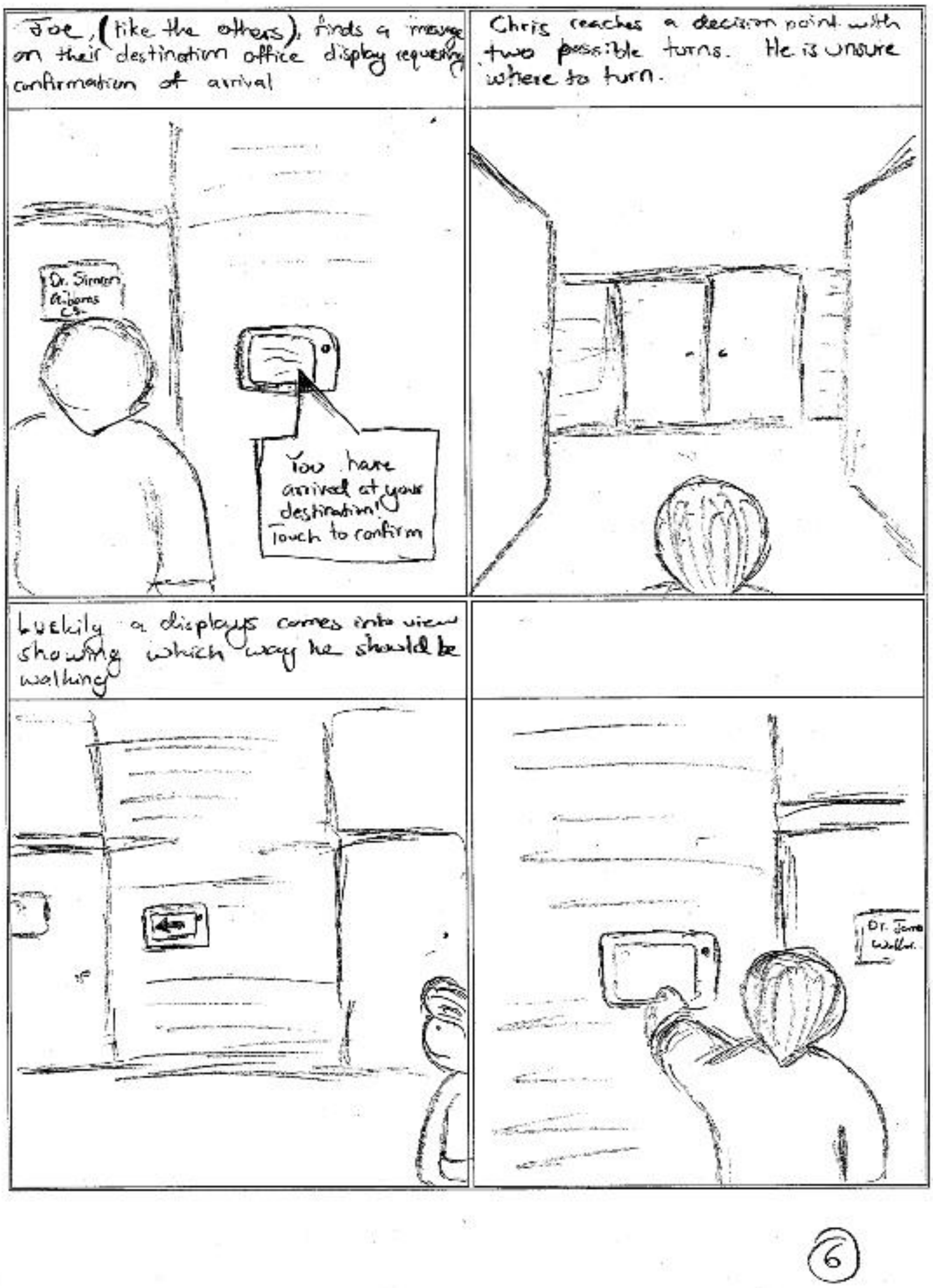

Sarah finds Lindsey on a Staff member list,
Sarah views a 3D route visualization a map, and also requests assistance from graphical arrows on fixed displays en-route.
3D
MAP
She also decides that she wants to view the directions on her mobile phone via QR code
Sarah brings up the 2D map she had viewed on the kiosk and begins to walk to Lindsey's office
2


Joe enters Infolab and finds the receptionist is busy. He also notices a kiosk display saying "Need help with directions" but it's being used.
Need help with directions
He is late so he begins finding his way to Simon's office by following on-the-wall signs. He's not sure where the office is located.
C-FLOOR
Joe is unsure of his current location but finds a fixed display outside one of the offices which he can use to receive navigation assistance.
C21
Need help
Joe finds Simon on a staff member list and views a map, 3D route visualization and also decides to request graphical arrows on the fixed displays along his route.
MAP
3D
3


Joe begins to walk to Simon's office by following the arrows and also by having gained an understanding of his route
Chris has finished with his group meeting and is about to go look for his supervisor James. Unsure of where James's office is, he decides to seek assistance using a fixed display
C4
CS3
Chris has used the fixed displays for navigation support before. He just finds it easier to request graphical arrows along his route.
After having followed directions (map) on her phone for a few minutes, Sarah notices the first display showing her arrow. She decides to follow them.
CS2
C18
5


After 2 displays with arrows Sarah notices a visitor (Joe) interacting with one of the displays along her path.
Sarah passes Joe, His display does not show an arrow to Sarah, but the following display shows Sarah's arrow.
Further down the route Sarah notices an additional arrow on one of the displays, not belonging to her, ie. it is Chris's arrow
Joe reaches a decision point but there are no displays to indicate a turn. However he remembers from viewing the 3D Visualization and map that he has to turn right.

5


Joe, (like the others), finds a message on their destination office display requesting confirmation of arrival
Dr. Simon Ribeiros CS.
You have arrived at your destination! Touch to confirm
Chris reaches a decision point with two possible turns. He is unsure where to turn.
Luckily a displays comes into view showing which way he should be walking
6

E.2 Participant Information Document

Dear Participant,

You are being invited to participate in a user study which involves an indoor navigation system prototype. The information presented in this document describes why the research is being carried out and what it will involve.

Contact information:
Faisal Taher
E-mail: f.taher@comp.lancs.ac.uk
Mobile: 07854314890

What is the purpose of the study?

Visitors in building locations often face challenges in finding their way, such as misunderstanding/neglecting signs and floor plans, forgetting directions and becoming confused by the building layout. In addition, visitors are generally limited to viewing static signage (e.g. signs on the wall) and asking others for directions. However, advances in digital technology are enabling new possibilities and novel methods of supporting users within buildings. Here, we investigate how digital display systems and mobile devices can offer useful and usable navigation support to visitors in such locations.

What will the study involve?

The study, which will take approximately 60 minutes, will involve the following stages:

Stage 1	You will be briefed regarding what you'll need to do during the study
Stage 2	You will be given a task sheet to carry out some tasks, e.g. use a touch screen display to find a lecturer, view a 3D route visualization to his/her office, etc.
Stage 3	Following the tasks, we will discuss your experiences about using the system, etc.
Stage 4	Short questionnaire

During the study you will be recorded with a camera for analysis purposes (e.g. for transcripts, analyzing participant behaviour, etc.).

Expenses and payments

We are very grateful for your participation and you will be paid £7 for the study

Will my participation be kept confidential?

Yes. All information will be kept confidential, including questionnaire data, recordings and photographic data. All data will also be kept anonymous in any reports or presentations that may result from this study

What will happen to the results of the study?

The results and findings will be analyzed for use as part of my PhD research, including conference papers, journal articles, presentations, thesis, etc. You will not be identified in any publication unless you have consented to release such information. All information will also be kept genuine and accurate.

Thank you for taking the time to read this document, please do not hesitate to contact me with any questions, issues or if you need more details.

Have a nice day ☺

E.3 Task Sheets

Trial task

Please remember to **think out loud** as you are carrying out the following tasks

1. On the touch screen Kiosk display, locate staff member **"Keith Cheverst" in** office number **C42**. Touch to select

2. Touch to select the **"Show me a map"** button to view map-based directions to Keith's office.

   You are viewing a map of your current location on your current floor. Touch to select the **"Show next step"** button to view directions on the floor your destination is located.

   Take some time to observe the maps

3. Touch to select the **"Show me a 3D visualization of my route"** button to view your route to Keith's office.

4. Touch to select the **"Request navigation arrows to display along my route"** button

5. Touch to select the **"View on mobile device"** button.

6. Using the phone, try and fit the image in the viewfinder on the mobile phone. Once a URL shows up, tap it on the phone to go to the website

7. View the two maps and 3D route visualization on your mobile phone and take some time get used to the mobile phone controls like:

   a. Zooming in and out of the map
   b. Playing and pausing the 3D visualization

Main task

Please remember to **think out loud** as you are carrying out the following tasks

1. On the touch screen Kiosk display, locate staff member **"Chris Needham"** in office number **C44**. Touch to select

2. Touch to select the **"Show me a map"** button to view map-based directions to Chris's office.

   You are viewing a map of your current location on your current floor. Touch to select the **"Show next step"** button to view directions on the floor your destination is located.

   Take some time to observe the maps

3. Touch to select the **"Show me a 3D visualization of my route"** button to view your route to Chris's office.

4. Touch to select the **"Request navigation arrows to display along my route"** button

5. Touch to select the **"View on mobile device"** button.

6. Using the phone, try and fit the image in the viewfinder on the mobile phone. Once a URL shows up, tap it on the phone to go to the website

7. Please walk to Chris's office using the map and 3D route visualization on the mobile phone and also look out for situated displays showing graphical arrows along your route.

E.4 Questionnaire

Please tick or circle appropriately and add any comments that you may have

Age: ___________ Occupation/Degree:____________________________________

Please rate your expertise with using technology:

- ☐ Inexperienced
- ☐ Some knowledge
- ☐ Average
- ☐ Above average
- ☐ Expert

Comments:

I found it useful to use the **Kiosk display** near the entrance to the Infolab21 building

1. Strongly disagree
2. Disagree
3. Undecided
4. Agree
5. Strongly agree

Comments:

I found it useful to view navigation content (e.g. 3D route visualization, map) on a **mobile phone** along my route

1. Strongly disagree
2. Disagree
3. Undecided
4. Agree
5. Strongly agree

Comments:

I found it useful to view graphical arrows on **situated displays** along my route

1. Strongly disagree
2. Disagree
3. Undecided
4. Agree
5. Strongly agree

Comments:

In the future, I would use the following to receive navigation support (**tick all that apply**):

- ☐ Kiosk display near the entrance
- ☐ Mobile phone
- ☐ Situated displays

Comments:

I would be useful to have this type of navigation support in other buildings (e.g. more complex institutions such as hospitals, shopping centres, government buildings, etc.)

1. Strongly disagree
2. Disagree
3. Undecided
4. Agree
5. Strongly agree

Comments:

My preferred type of content on the **Kiosk display** was the following (**tick all that apply**):

- ☐ Digital 2D map
- ☐ 3D route visualization

Comments:

My preferred type of content on the **mobile phone** was the following (**tick all that apply**):

- ☐ Digital 2D map
- ☐ 3D route visualization

Comments:

I would be willing to pay for internet on my personal mobile phone

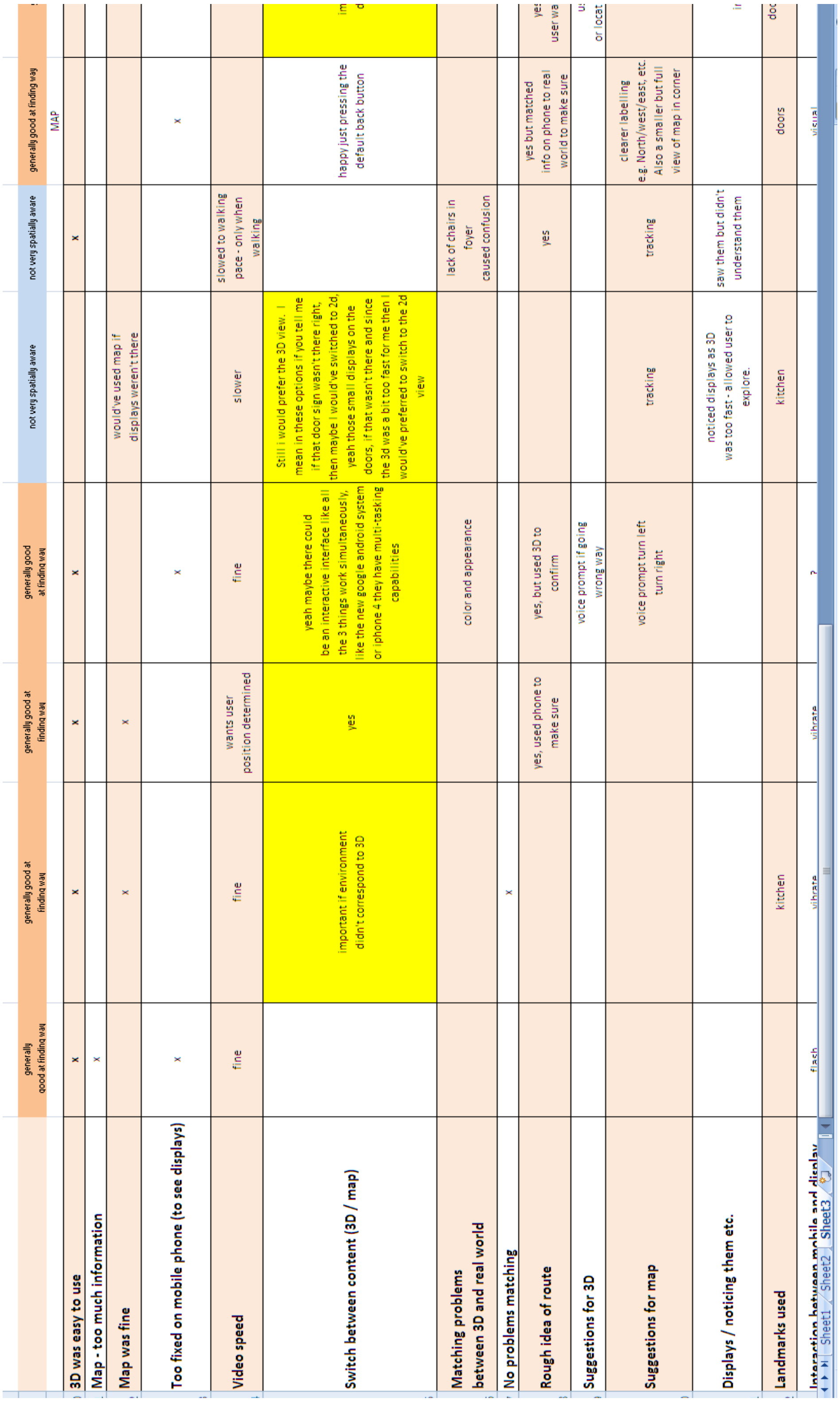
1. Strongly disagree
2. Disagree
3. Undecided
4. Agree
5. Strongly agree

Comments:

Additional Comments:

E.5 Grounded Theory Approach

The diagram below represents the use of an Excel spreadsheet to record important categories that emerged from the user study transcriptions. It also shows tags such as user quotes or observed behaviours relevant to the categories



	generally good at finding way	generally good at finding way	generally good at finding way	generally good at finding way	not very spatially aware	not very spatially aware	generally good at finding way	
							MAP	
3D was easy to use	x	x	x	x		x		
Map - too much information	x							
Map was fine		x	x		would've used map if displays weren't there			
Too fixed on mobile phone (to see displays)	x			x			x	
Video speed	fine	fine	wants user position determined	fine	slower	slowed to walking pace - only when walking		
Switch between content (3D / map)		important if environment didn't correspond to 3D	yes	yeah maybe there could be an interactive interface like all the 3 things work simultaneously, like the new google android system or iphone 4 they have multi-tasking capabilities	Still i would prefer the 3D view. I mean in these options if you tell me if that door sign wasn't there right, then maybe I would've switched to 2d, yeah those small displays on the doors, if that wasn't there and since the 3d was a bit too fast for me then I would've preferred to switch to the 2d view		happy just pressing the default back button	im d
Matching problems between 3D and real world				color and appearance		lack of chairs in foyer caused confusion		
No problems matching		x						
Rough idea of route			yes, used phone to make sure	yes, but used 3D to confirm		yes	yes but matched info on phone to real world to make sure	yes user wa
Suggestions for 3D				voice prompt if going wrong way				us or locat
Suggestions for map				voice prompt turn left turn right	tracking	tracking	clearer labelling e.g. North/west/east, etc. Also a smaller but full view of map in corner	
Displays / noticing them etc.					noticed displays as 3D was too fast - allowed user to explore.	saw them but didn't understand them		in
Landmarks used		kitchen			kitchen		doors	doc
Interaction between mobile and display	flash	vibrate	vibrate	?			visual	

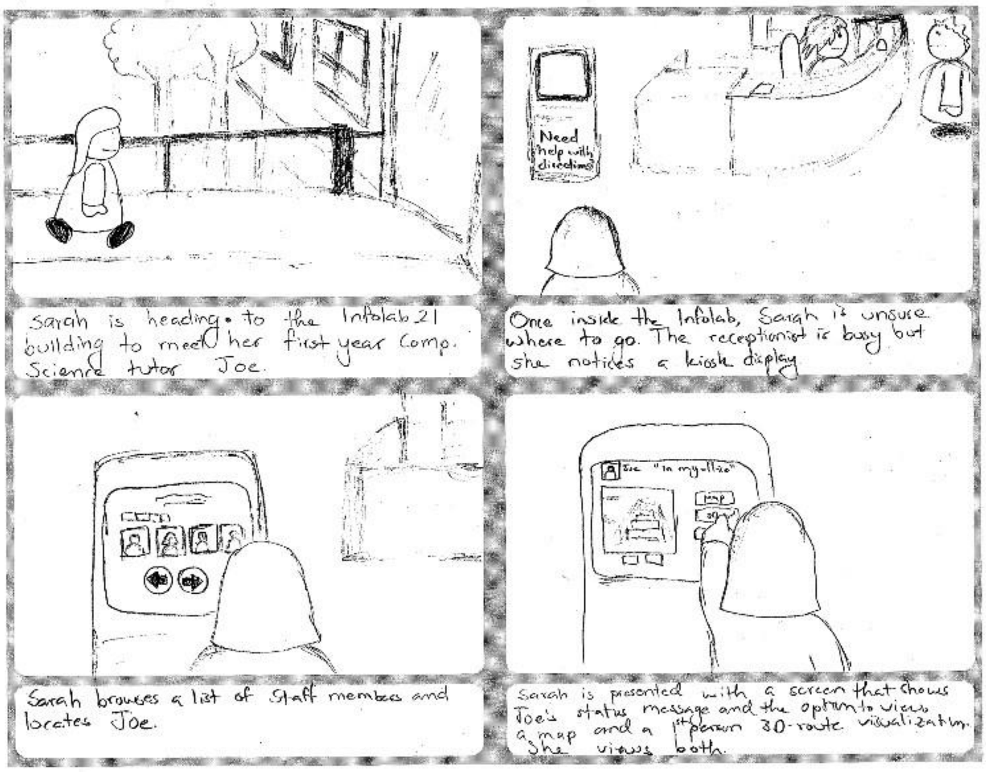
Sheet1 Sheet2 Sheet3

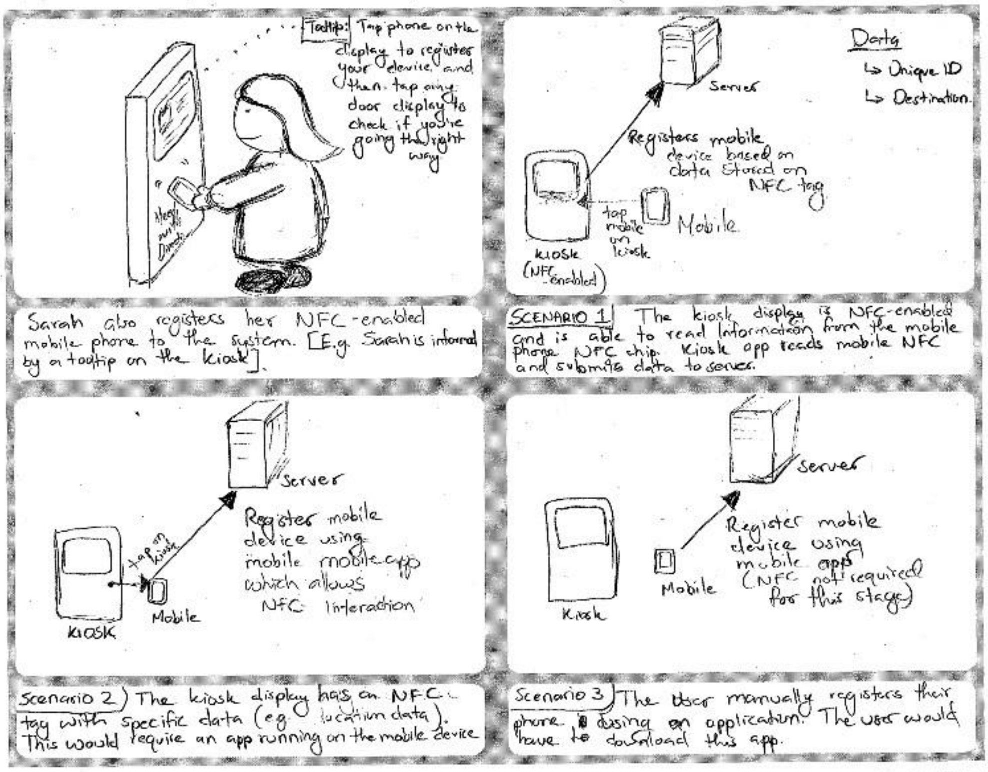
Appendix F

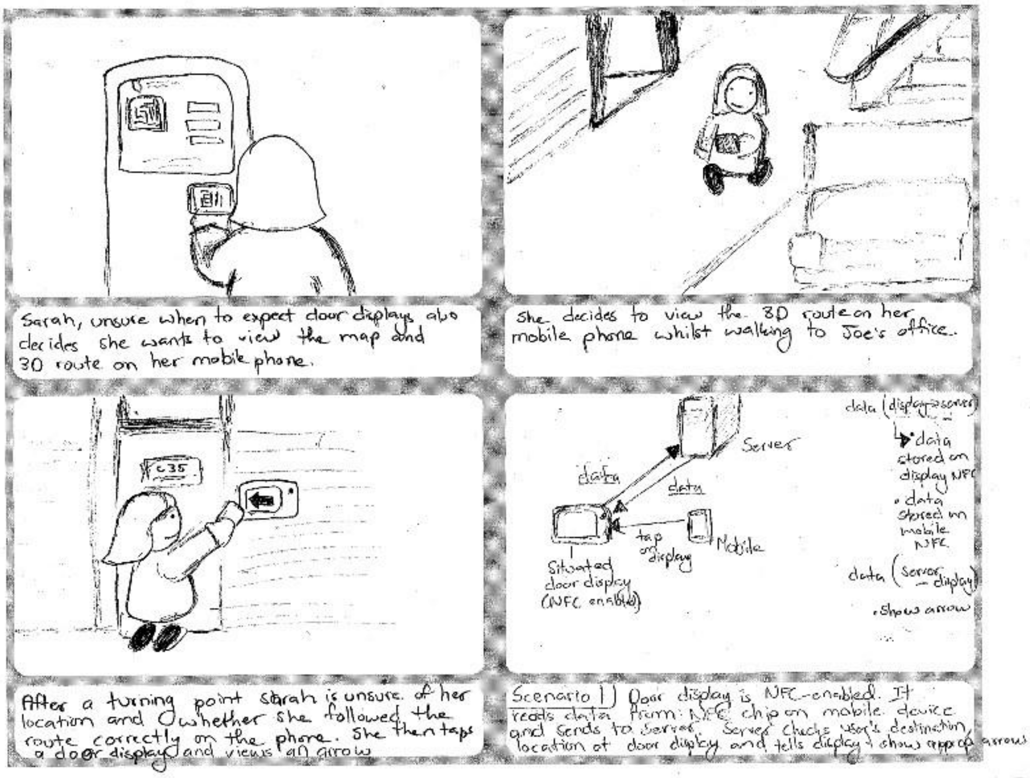
User Study Six

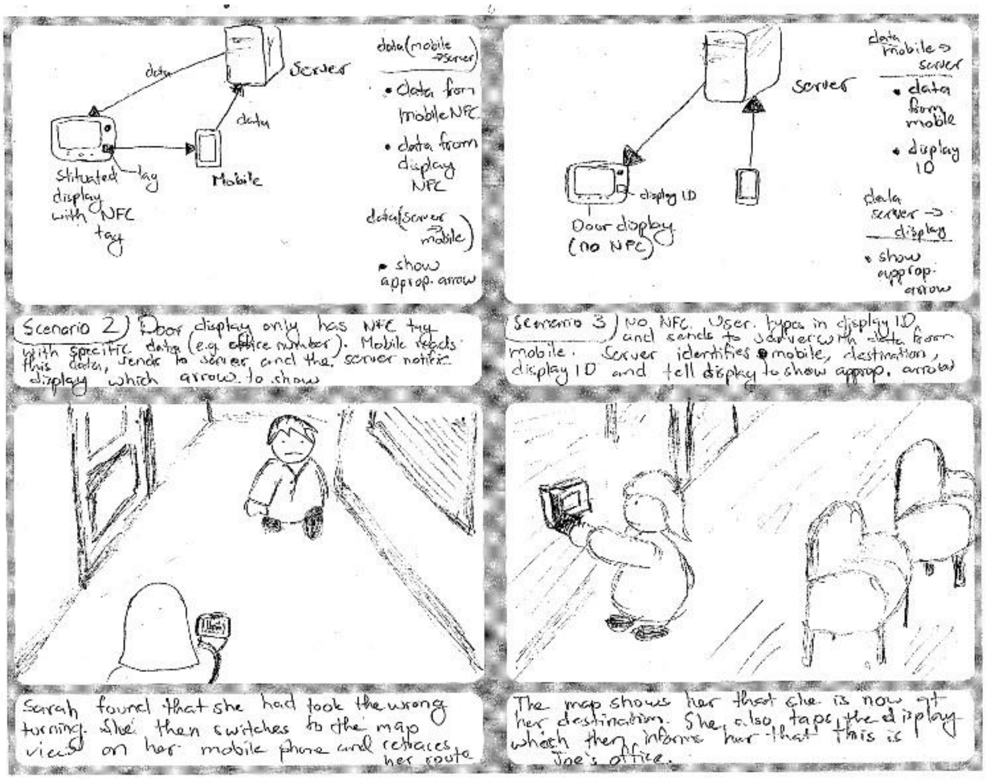
F.1 Storyboards

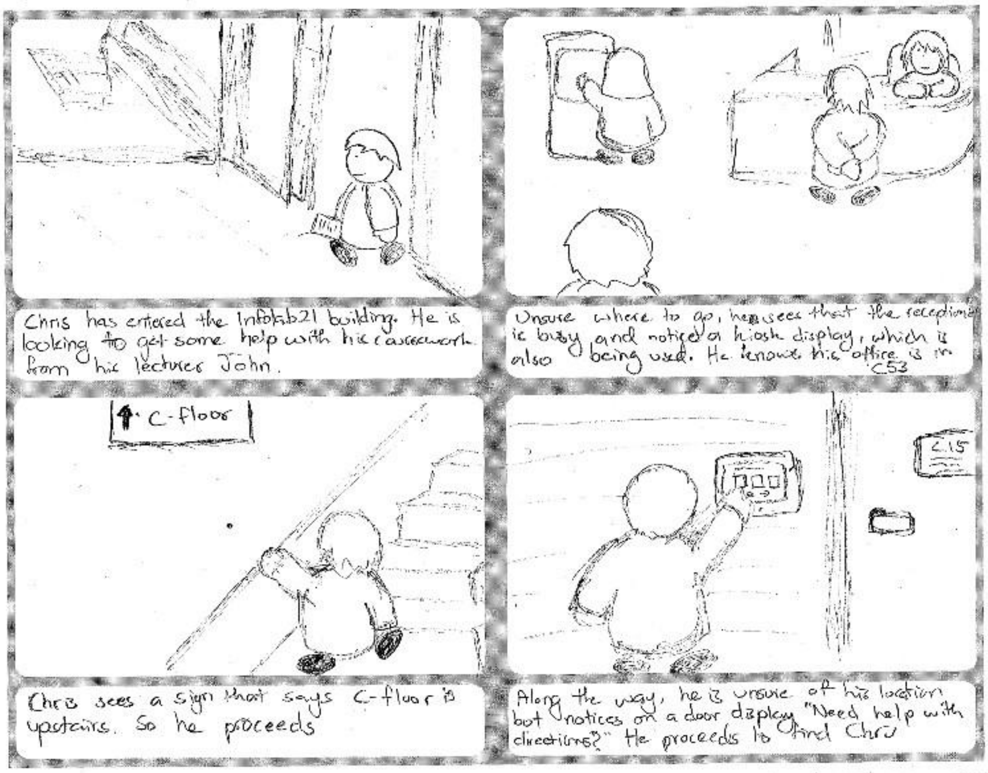
The following storyboards informed the interaction styles and the communication methods of an NFC-based approach to achieve location-aware navigation support. The storyboard also aided in the way in which the prototype Hermes2 navigation system was configured.

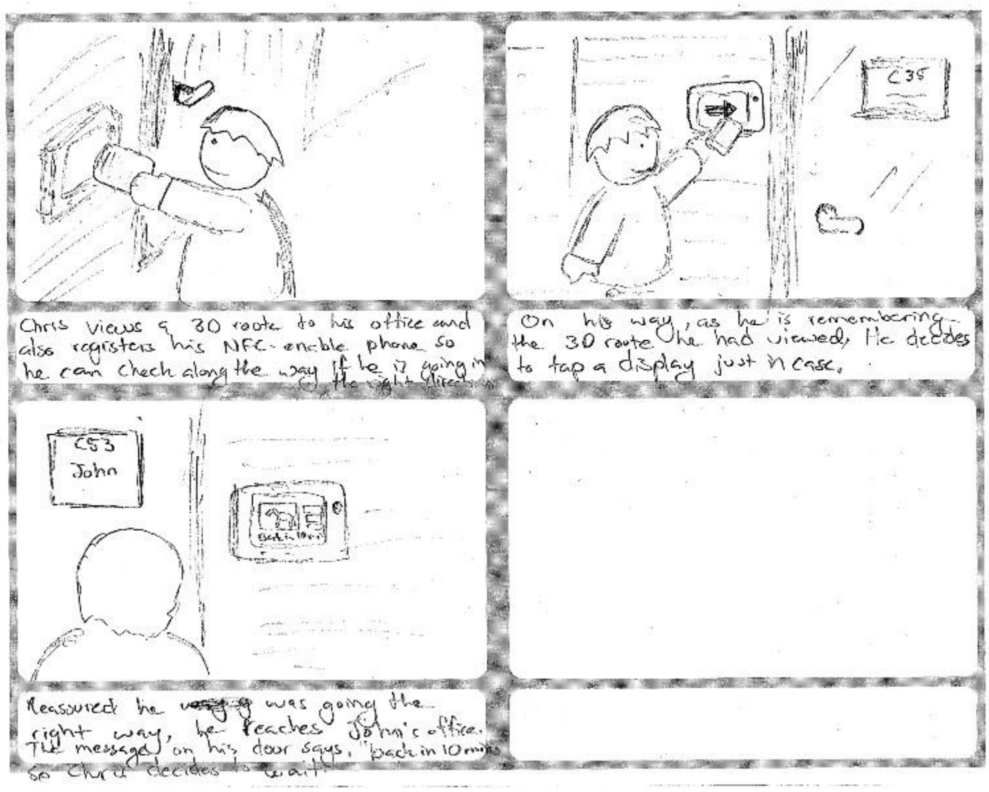



Tooltip: Tap phone on the display to register your device and then tap any door display to check if you're going the right way
Sarah also registers her NFC-enabled mobile phone to the system. [E.g. Sarah is informed by a tooltip on the kiosk].
Data
↳ Unique ID
↳ Destination.
Server
Registers mobile device based on data stored on NFC tag
tap mobile on kiosk
Mobile
kiosk (NFC-enabled)
SCENARIO 1) The kiosk display is NFC-enabled and is able to read information from the mobile phone NFC chip. Kiosk app reads mobile NFC and submits data to server.
Server
Register mobile device using mobile mobile app which allows NFC interaction
tap on kiosk
Mobile
KIOSK
Scenario 2) The kiosk display has an NFC tag with specific data (e.g. location data). This would require an app running on the mobile device
Server
Register mobile device using mobile app (NFC not required for this stage)
Mobile
Kiosk
Scenario 3) The user manually registers their phone using an application. The user would have to download this app.


Sarah, unsure when to expect door displays also decides she wants to view the map and 3D route on her mobile phone.
She decides to view the 3D route on her mobile phone whilst walking to Joe's office.
C35
After a turning point Sarah is unsure of her location and whether she followed the route correctly on the phone. She then taps a door display and views an arrow
Server
data
data
tap on display
Mobile
Situated door display (NFC enabled)
data (display→server)
↳ • data stored on display NFC
• data stored on mobile NFC
data (server→display)
• show arrow
Scenario 1) Door display is NFC-enabled. It reads data from NFC chip on mobile device and sends to server. Server checks user's destination, location of door display and tells display to show approp. arrow


data
Server
data
Situated display with NFC tag
tag
Mobile
data (mobile → server)
• data from mobile NFC
• data from display NFC
data (server → mobile)
• show approp. arrow
Server
display ID
Door display (no NFC)
data mobile → server
• data from mobile
• display ID
data server → display
• show approp. arrow
Scenario 2) Door display only has NFC tag with specific data (e.g. office number). Mobile reads this data, sends to server and the server notifies display which arrow to show
Scenario 3) No NFC. User types in display ID and sends to server with data from mobile. Server identifies mobile, destination, display ID and tell display to show approp. arrow
Sarah found that she had took the wrong turning. She then switches to the map view on her mobile phone and retraces her route
The map shows her that she is now at her destination. She also taps the display which then informs her that this is Joe's office.


Chris has entered the Infolab21 building. He is looking to get some help with his coursework from his lecturer John.
Unsure where to go, he sees that the receptionist is busy and noticed a kiosk display, which is also being used. He knows his office is in C53
C-floor
Chris sees a sign that says C-floor is upstairs. So he proceeds
C15
Along the way, he is unsure of his location but notices on a door display "Need help with directions?" He proceeds to find Chris


C35
Chris views a 3D route to his office and also registers his NFC-enable phone so he can check along the way if he is going in the right direction
On his way, as he is remembering the 3D route he had viewed, He decides to tap a display just in case.
C53
John
Reassured he was going the right way, he reaches John's office. The message on his door says, "back in 10 mins" so Chris decides to wait.

F.2 Participant Information Document

Participant Information Sheet

Exploring requirements for indoor navigation support using mobile and fixed displays and digital content

Dear Participant,

This is an invitation to a user study investigating interaction design requirements for indoor navigation support. Before you make any decisions, please take your time to read the information contained in this document. It will give you insight in to this research, and involved activities.

Feel free to contact us with any questions in case any of the information is unclear.

Researcher:

Faisal Taher (f.taher@lancaster.ac.uk)

Project Supervisor:

Keith Cheverst (k.cheverst@lancaster.ac.uk)

Project Title:

Exploring interaction design requirements for indoor navigation support using mobile and fixed displays

---

What is the purpose of this study?

The purpose of the study is to investigate design requirements for supporting visitors concurrently (i.e. at the same time) by using a 'swipe' interaction using a mobile phone and digital door displays. A typical example of a swipe interaction involves swiping your card to go through the barriers at a train/metro station.

Why am I suitable to be a participant?

The study requires feedback from participants who have no experience of the Infolab21 building, where the study will be carried out. This will help ensure that information gathered during the study will not be influenced by pre-existing knowledge of the building environment. We also require 15 participants with a near-equal male to female ratio.

Is the participation voluntary?

Yes, it is entirely voluntary. You can also withdraw at any stage of the study. However this would automatically mean that no payments will be made for your participation. To be sure that you can participate in this study happily and get your reward we advise you to read this document carefully and discuss with the researcher any questions you may have before you sign the consent form.

- You will be treated with respect and dignity at every phase of the study.
- You will be treated with honesty, integrity, openness, and straight forwardness in all phases of the research, including a guarantee that you will not unknowingly be deceived during the course of the research.
- You should sense NO pressure, explicit or otherwise, to sign this contract.

Expenses and payments:

The participants of this study will be rewarded with £7. The reward is payable only if the participant decides to complete the study, signs the consent form and does not withdraw from the experiment until it is finished.

What does the study involve?

During the study, you will be asked to carry out a set of tasks provided to you on task sheets. In brief, the tasks will involve you to:

- Answer a short questionnaire
- Find directions to a staff member's office by using touch-screen displays
- Walk to the staff member's office (you won't be asked to walk into the office or interact with any staff)
- Use touch-screen displays and a mobile phone to view digital maps, signage and 3D route visualizations.
- Partake in a discussion about your experience and thoughts (i.e. semi structured interview).
- Answer another short questionnaire

Confidentiality:

You as well as all other participants will remain anonymous. Any information provided by you will remain confidential. All the participants will be referred to in the reports resulting from this study by code names (e.g. P1, P2, P3, etc).

Problems and Complaints:

In case any issues arise or you wish to complain about any part of the study you are involved with, feel free to contact the researcher using the e-mail address from the top of this document. If this does not satisfy you and you wish to file a formal complaint, please contact the project supervisor, Dr Keith Cheverst. A copy of the participant information sheet and photocopies of your signed consent forms are also available upon request for a period of 24 months.

What happens after the study?

The data collected through this study will be analysed, and the conclusions produced will allow the researchers to reflect on the design requirements for the swipe interaction technique. The study will be concluded with a written report, summarising the findings.

Thank you for your time.

Consent Form

Name: ________________________________

☐ I am at least 18 years old.

☐ I have read and understood the consent form.

☐ I understand the nature of this study and wish to participate.

☐ I allow the recording of video and audio for data analysis.

☐ I understand that I can withdraw at any time.

☐ I understand that all data will be anonymous.

______________________________ ________________________

Participant's Signature Date

_____________________________ ________________________

Researcher's Signature Date

F.3 Task Sheets

Participant task sheet: Trial task

Step 1

You are looking for a member of staff in the building.

- Find **John Evans**, in office number **C60a** on the touch screen display. Touch to select.

Step 2

You are reading John's status message to find out where he is in the building, or if he is in the building at all.

- Read the status message on the top-left corner of the screen, next to the profile thumbnail

---

Step 3

You decide to view a map to find out where you are, and where your destination (John's office) is located in the building.

- Press the **Show me a map** button to view the map. The map you are looking at represents the floor level you are currently on, and where you are (marked with a "You are here" marker).
- Press the **Full-screen** button for a full-screen (larger) view.
- Press the **Show next step** button to view the floor level where John's office is located. Note that the destination is marked with a "Your destination" marker
- Once you have an understanding of where you current and destination locations are, press **Exit full-screen.**

Step 4

You decide to view a first-person 3D visualization of your route from your current location to John's office.

- Press the **Show me a 3D visualization of my route** button to view the 3D route visualization. Wait for the visualization clip to finish.

Step 5

You then decide that you want to receive some help whilst you are walking to John's office.

- Press the **Help me along the way** button.
- Swipe the Nokia N9 mobile phone on the tag, as marked on the display. Please wait for the phone to vibrate and then hold for about 2 seconds.
- Wait for the confirmation message on the touch screen display

Along your route there will be medium sized displays installed beside office doors. You can carry out a similar swipe interaction in order receive navigation support along your route.

Step 6

You also decide that you want to view the map and the 3D visualization on the Nokia N9 mobile phone. Please prompt the experimenter to set this up for you.

Participant task sheet: Main task pt. I

Step 1

You are looking for a member of staff in the building.

- Find **Steve Elliott** in office number **C50** on the touch screen display. Touch to select.

Step 2

You are reading Steve's status message to find out where he is in the building, or if he is in the building at all.

- Read the status message on the top-left corner of the screen, next to the profile thumbnail

Step 3

You decide to view a map to find out where you are, and where your destination (Steve's office) is located in the building.

- Press the **Show me a map** button to view the map. The map you are looking at represents the floor level you are currently on, and where you are (marked with a "You are here" marker)
- Press the **Full-screen** button for a full-screen (larger) view
- Press the **Show next step** button to view the floor level where Steve's office is located. Note that the destination is marked with a "Your destination" marker
- Once you have an understanding of where you current and destination locations are, press **Exit full-screen**

Step 4

You decide to view a first-person 3D visualization of your route from your current location to Steve's office.

- Press the **Show me a 3D visualization of my route** button to view the 3D route visualization. Wait for the visualization clip to finish.

Step 5

You then decide that you want to receive some help whilst you are walking to Steve's office.

- Press the **Help me along the way** button.
- Swipe the Nokia N9 mobile phone on the tag, as marked on the display.
- Wait for the confirmation message on the touch screen display

Along your route there will be medium sized displays installed beside office doors. You can carry out a similar swipe interaction in order receive navigation support along your route.

Step 6

You also decide that you want to view the map on the Nokia N9 mobile phone. Please prompt the experimenter to set this up for you.

Step 7

Using the map on the mobile phone, please walk to Steve Elliott's office in C50

Participant task sheet: Main task pt. II

Step 1

You are looking for another member of staff in the building.

- On the door display, press and select Steve Elliott.
- Press the **Get directions** button
- Find **Adam Baron** in office number **C13** on the touch screen door display. Touch to select.

Step 2

You are reading Adam's status message to find out where he is in the building, or if he is in the building at all.

- Read the status message on the top-left corner of the screen, next to the profile thumbnail

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Step 3

You decide to view a map to find out where you are, and where your destination (Adam's office) is located in the building.

- Press the **Show me a map** button to view the map. The map you are looking at represents the floor level you are currently on, and where you are (marked with a "You are here" marker).
- Press the **Full-screen** button for a full-screen (larger) view.
- Note that the destination is marked with a "Your destination" marker
- Once you have an understanding of where you current and destination locations are, press **Exit full-screen**

Step 4

You decide to view a first-person 3D visualization of your route from your current location to Adam's office.

- Press the **Show me a 3D visualization of my route** button to view the 3D route visualization. Wait for the visualization clip to finish.

Step 5

You then decide that you want to receive some help whilst you are walking to Adam's office.

- Press the **Help me along the way** button.
- Swipe the Nokia N9 mobile phone on the tag, as marked on the display.
- Wait for the confirmation message on the touch screen display

Along your route there will be medium sized displays installed beside office doors. You can carry out a similar swipe interaction in order receive navigation support along your route.

Step 6

You also decide that you want to view the first-person 3D route visualization on the Nokia N9 mobile phone. Please prompt the experimenter to set this up for you.

Step 7

Using the 3D route visualization on the mobile phone, please walk to Adam Baron's office in C13

F.4 Questionnaire

Participant # _______

Age: ______

Gender: ______

Please tick or circle appropriately and add any comments that you may have

I am familiar with using a Smartphone (e.g. an iPhone, Samsung Galaxy)

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
O	O	O	O	O

Please give examples of the types of Smartphones you have used:

I am familiar with using public displays (e.g. Kiosk displays, information displays at a train station)

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
O	O	O	O	O

Please give examples of the types of displays you have used:

I am familiar with using a Smartphone to interact with a public display?

Strongly disagree — Disagree — Neither agree nor disagree — Agree — Strongly agree

Comments:

I am familiar with swiping a card to get through the barriers, for example, at a train/metro/tube station.

Strongly disagree — Disagree — Neither agree nor disagree — Agree — Strongly agree

Please give examples of places where you have done this:

I am familiar with using digital map applications (e.g. Google maps, street-view, in-car GPS).

Strongly disagree — Disagree — Neither agree nor disagree — Agree — Strongly agree

Please give examples of the types of applications you have used:

I am familiar with using digital map applications inside building environments (e.g. Shopping centre, hospital building)

Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
○	○	○	○	○

Please give examples of the types of applications you have used:

Any additional comments:

F.5 Grounded Theory Approach

The diagram below represents the use of an Excel spreadsheet to record important categories that emerged from the user study transcriptions. It also shows tags such as user quotes or observed behaviours relevant to the categories.