Exploring User Preferences for Indoor Navigation Support through a Combination of Mobile and Fixed Displays

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ABSTRACT
In this paper we explore, through a formative study, user preferences for indoor navigation support using a combination of mobile and fixed displays along with a range of navigation content such as digital 2D maps, 3D route visualizations (presented as continuous media from a first person perspective) and graphical directional arrows. It is well-established that visitors within complex building architectures (e.g. hospitals) often face challenges in finding their way and are limited to using traditional static signage or asking others for directions. Recent developments in mobile and pervasive technology however, are enabling a range of possibilities and augmenting the way in which users receive digital navigation support. Here, we discuss a formative study involving 16 participants using the prototype Hermes2 Navigation System in order to inform the development of a useful and usable interactive indoor navigation system.

Author Keywords
Indoor navigation, mobile phones, digital displays, graphical directional signage, 3D visualization, digital maps.

ACM Classification Keywords
H5.2. Information interfaces and presentation (e.g., HCI): Graphical User Interfaces.

General Terms
Design, Experimentation, Human Factors

INTRODUCTION
Visitors within complex built environments often face challenges in finding their way, such as misunderstanding/neglecting signage and floor plans, forgetting directions and becoming disoriented from poor architectural communication [1, 16]. Furthermore, visitors are generally limited to using traditional static signage or asking others for directions. In recent years however, advances in pervasive and digital interactive systems are addressing such challenges and enabling novel methods of supporting navigation within buildings. The motivation of our group is to investigate how a combination of mobile and fixed displays along with a range of digital content can support visitors in an indoor environment. In more detail, we are interested in how visitors can be supported at the beginning of their navigation task, as well as whilst en-route to their destination location (similar to an in-car GPS system). In this paper we focus on user preferences for indoor navigation support using the prototype Hermes2 Navigation System, which consists of an experimental set-up of the following components:

- A digital kiosk display (figure 1a) and a deployment of fixed digital displays known as Hermes2 (figure 1b)
- An HTC Desire mobile phone
- Digital navigation content such as 2D maps, 3D route visualizations (presented as continuous media from a first person view) and graphical directional arrows.

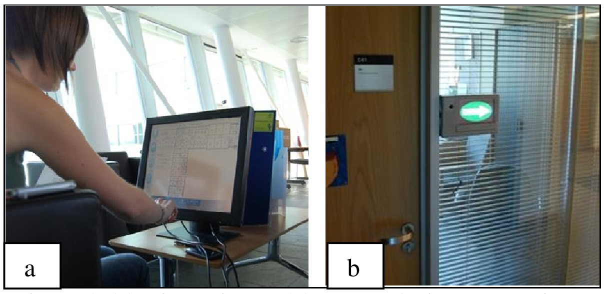

Figure 1. (a) Kiosk display (b) Hermes2 display showing a graphical directional arrow

To investigate user preferences for indoor navigation support using the experimental set-up described above, we have carried out a formative study with 16 participants in the Infolab21 building at Lancaster University. To demonstrate the functionality of the prototype Hermes2 Navigation System, consider the following scenario:

Marie decides to wander to the Computing department building to see her Java module lecturer Dr. Joe Anderson.

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She does not, however, remember his office or contact number. Marie approaches the reception desk and finds that the receptionist has left a note saying "Back in 15 minutes". Beside the desk however, she notices a kiosk display is labeled "Need help with directions?" Marie decides to use this display and locates Joe on a list of lecturers. She is then presented with a screen which enables her to view navigation information. She notices the message "In my office" beside Joe's profile photograph, which he has left on his door display. Marie then views a digital 2D map and a 3D visualization to find her route to Joe's office. Marie also chooses to request graphical arrows to show on fixed displays along her route. Before setting off, Marie presses the "View on Mobile Device" button, takes out her mobile phone and scans the barcode shown on the display using a barcode scan application. She is then directed to a website on her mobile phone that shows her the content she had viewed on the kiosk display (i.e. the 2D map and 3D visualization). Marie then begins to walk towards Joe's office by choosing to follow the 3D visualization on her mobile phone. Whilst walking she comes across a digital display showing a semi-transparent graphical arrow, which she had requested on the kiosk display. At this point she decides to stop following the visualization on her phone and simply follow the arrows on the displays and successfully finds Joe's office.

During the formative study, participants underwent a similar procedure as described in the above scenario, that is, they were required to initially interact with a touch-screen kiosk display (connected to a laptop) placed next to the building entrance. Participants then viewed navigation content to receive directions to a lecturer's office and, furthermore, they used a combination of a mobile phone and fixed displays to receive navigation support en-route. The study was carried out using an ecologically valid approach, that is, we recruited participants who were unfamiliar with the environment. The Hermes2 Navigation System set-up was based around a Wizard of Oz [14] approach as we did not use a location model. Thus, the route to the lecturer's office during the study was pre-determined rather than dynamically generated.

The study presented in this paper provides insights into our research by addressing the following questions:

1. What preferences do users have when receiving support from mobile and fixed displays and from navigation content such as digital 2D maps, 3D route visualizations and graphical arrows?
2. In what ways can mobile and fixed displays, as well as a range of navigation content, be effectively combined to support users in indoor environments?

The sections of this paper are structured as follows. We proceed to describe relevant past research with navigation systems and the types of knowledge gained from spatial representations. Next, we describe the experimental set-up used in our user study, followed by the study approach. The results are then presented, followed by a discussion of findings, plans for future work and a conclusion.

BACKGROUND

Conducted Studies

We have previously carried out five separate formative user studies, which enabled us to gain an understanding of user preferences and requirements for the supporting components of the prototype Hermes2 Navigation System. The formative study presented in this paper builds on this work (see summaries below, and [9, 22, 23] for details).

Study 1

The first (questionnaire-based) study, carried out in 2006, investigated the extent to which Hermes2 display owners would be prepared to share their displays to assist navigation of visitors to the department [9]. The study revealed positive display owner attitudes in sharing their displays providing that they maintained appropriate control, that is, display owners wanted to be given the means to stipulate that an important message set by themselves on the display would not be occluded by navigation content such as a graphical arrow.

Studies 2 and 3

The next two studies investigated the utility of presenting a combination of 2D and 3D content (2D maps and 3D route visualizations) to support indoor navigation [22, 23]. We also explored whether users would find it helpful to use a mobile phone to view this type of content en-route. The second study, conducted in August 2008, involved eight participants (4m, 4f) and technologies such as the kiosk display and a mobile phone. The follow-on (third) study involved six participants (3f, 3m) and was carried out in January 2009 as no significant results were obtained regarding mobile phone use (i.e. in the second study, participants were able to decide whether to use a mobile phone to view navigation content). Results demonstrated that: (a) participants found it useful to view a combination of 2D and 3D content and (b) participants experienced a sense of security using a mobile phone to view navigation content en-route.

Study 4

In this study we explored whether Hermes2 display owners would be willing to share their displays to show navigation-related content (e.g. graphical directional arrows) and also share information on the kiosk display (e.g. the route to their office, profile photographs, display messages, etc.) [23]. Questionnaires were issued to 12 participants (8f, 4m) in March 2009. Participants included lecturers, administrative staff and researchers. Results showed that display owners were generally comfortable with display sharing and also sharing information on the kiosk display. These findings echo previous results from the first study and have provided encouraging feedback with regards to display sharing and, consequently, motivating the development of an indoor navigation system.

Study 5

In this study, we explored whether users would find it useful to view 2D and 3D navigation content at the beginning of their navigation task and receive assistance en-route using a mobile phone and graphical directional arrows on fixed displays [22, 23]. The study involved 10 participants (5m, 5f) and was carried out in March 2009. However, due to GUI-related limitations on the kiosk display, no significant results were drawn in terms of the combined use of mobile and fixed displays. The study simply re-confirmed the utility of presenting a combination of 2D and 3D navigation content and the sense of security experienced by participants when using a mobile phone.

Study 6

The sixth study was carried out in July 2009 with three participants (1f, 2m) [23]. We explored whether users would find it useful to view graphical directional arrows on fixed displays. Results showed preferences relating to: (a) the placement of displays, (b) the type of content presented and (c) the types of interaction users would prefer. Participants suggested, for instance, that it would be useful to supplement the graphical arrows on the fixed displays with information about the user's progress along their route (e.g. number of remaining doors).

Past Research into Navigation Systems

Past research has included investigations into the utility and requirements for systems that support user navigation in both an outdoor and indoor context. The technologies involved have encompassed mobile as well as fixed display configurations along with two-dimensional and three-dimensional navigation content.

Chittaro and Nadalutti, for instance, investigate how an interactive 3D location-aware model of a building can be used to provide evacuation instructions on a mobile phone [5]. Two informal user evaluations revealed that such a model was promising in providing navigation information to users and confirmed the utility of a three-dimensional representation for navigation purposes. The m-LOMA system [15] is another example where the utility of three-dimensional information (based on VRML) on a mobile device is explored. The authors investigated, through a field experiment, how users orientate themselves and how users map between the three-dimensional view and the physical environment. Although results were promising (e.g. users were able to easily recognize buildings) the study revealed that requirements for a realistic three-dimensional map were high (e.g. inaccuracies in the three-dimensional representation can lead to trust issues).

In [8] Graham et al. addressed the mapping issue between the physical world and a mobile system during interaction with a context-aware mobile guide. Evaluations of two mobile guides were carried out [2, 4] and several interaction paradigms proposed. These can be used as possible and useful abstractions for use in designing context-aware mobile guides (e.g. a Chaperone can behave as an expert system that would take initiative away from users during interaction).

Seager and Fraser [20] addressed the issue of map alignment on mobile devices. A field experiment suggested that physical rotation of the mobile device (and thus, the map) is most effective when users were presented with a wider map. The study involved measures such as navigation performance, workload and spatial orientation tasks. Schoning et al. [21] describe the PhotoMap application, which is designed to support pedestrian navigation through means of capturing You Are Here maps by a GPS-enabled mobile phone. A user study provided encouraging feedback on the concept of using such maps for pedestrian navigation.

In [26] Willis discusses how technology used for navigation support can be limiting in terms of interaction between the user, technology and physical environment. This relates to: (a) the accuracy of positioning technology, (b) issues with user interpretation of represented versus real data and (c) environmental factors.

In an indoor context, Kray et al. have investigated requirements and constraints toward developing a location model to support navigation in a building environment with an infrastructure of situated displays [10]. General requirements were specified, that relate to general navigation, specific requirements for a particular domain and also technological constraints that result from technologies being used. In [11] Kray et al. describe the design for a prototype navigation system (i.e. the system was not deployed) named GAUDI. The system aimed to support public navigation by using wall-mounted situated displays that provide directional signage. The design of the system consists of a grid of wireless autonomous displays connected to a navigation server and it utilizes a location model where displays are represented as nodes, annotated with location-specific information. Routes are calculated using the A* routing algorithm. Lijding et al. [12] describe the Smart Signs system, which utilizes situated displays in an indoor environment to provide route directions (using graphical arrows) to users. The system was designed to accommodate several factors such as a user's mobility limitations, weather conditions and emergency situations such as fire or if a user requires medical attention.

Muller et al. [13] carried out two field studies in an outdoor environment to investigate pedestrian navigation support by using a deployment of situated public displays and mobile devices. The paper also addressed factors concerning user acceptance and usability. Participants in the field studies interacted with situated displays (designed for advertisements) to receive navigation support in combination with a mobile device in a shopping scenario. The authors found that users had a tendency to only use the mobile phone for navigation whilst walking; however, disoriented users were more willing to interact with a public display to view navigation information. In [18], Rukzio et al. investigated and evaluated the Rotating Compass, a public display for pedestrian navigation. An outdoor study (which involved interactions between a paper map, mobile phone and the public display) showed positive interaction possibilities with the Rotating Compass based on several measurement categories (e.g. task completion time, usability satisfaction, etc.).

Role of Spatial Representations in Navigation

Spatial knowledge is composed of three different forms: (a) landmark-recognition, (b) route-finding and (c) survey knowledge [7]. In general, experiencing the environment from a first person point of view enables users to recognize landmarks, followed by gaining route-finding knowledge. Survey knowledge of an environment can generally be gained through observation from an exocentric view (e.g. from a map) or from long term exposure to a first person view. Thorndyke and Hayes-Roth describe survey knowledge as being able to apply configurational relationships of an environment into a single model [24]. It is also known to be the highest form of spatial knowledge.

A number of past studies have investigated, as well as compared, two-dimensional (i.e. map-based) and three-dimensional representations. Ruddle et al. [17] state that users who gain navigational knowledge from an extended three-dimensional experience are able to match the knowledge gained from a normal two-dimensional map. In contrast, Satalich [19] stated that map learners perform somewhat better than those exposed to three-dimensional representations. The contrasting arguments are linked to differences in the length of time that users were exposed to each representation.

THE EXPERIMENTAL CONFIGURATION

To investigate user preferences for indoor navigation support using a combination of mobile and fixed displays, we used an experimental set-up composed of the Hermes2 system and the prototype Hermes2 Navigation System.

Hermes2 System

The Hermes2 System has previously been discussed in [6, 22, 23]. Here we provide a brief description of the system, which was designed to support awareness in an office-based environment by adapting the idea of for example, sticking a note on a door saying "Gone for coffee". The system, initially known as Hermes, was deployed in 2002 and consisted of PDA displays fixed adjacent to the office doors of members of the Computing Department at Lancaster University. In 2006 the Computing Department moved to a newly constructed building and a new set of working prototypes were deployed. The new deployment, known as Hermes2, included several hardware improvements over Hermes (e.g. larger displays) and consists of a test-bed of 40 displays deployed along two corridors (see figure 2).

The Hermes2 Application

The Hermes2 application allows display owners to, for instance, set a temporary text or multimedia message on their display (e.g. a photograph of their current conference venue) by using their personal web portal, by SMS by using a mobile phone or by e-mail.

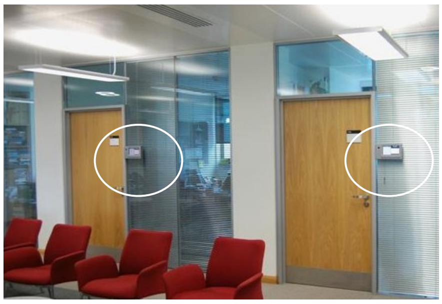

Figure 2. The deployment environment of Hermes2 displays

Owners are also able to view messages that are left by visitors by using their personal web-portal. Visitors are able to set text (e.g. "Hi, it's John, came to see you at 12.15 today") and scribbled messages. The Hermes2 application is based around a Model View Controller model. The Model consists of a MySQL database, the View consists of the graphical user interface and the Controller provides functionality for messaging.

Hermes2 Navigation System

The Graphical User Interface

The Graphical User Interface for the prototype Hermes2 Navigation System was designed to explore whether participants in the formative study would find it useful to view navigation content at the beginning of their navigation task. Furthermore, we explored whether participants would find it useful to "take-away" content to view en-route to their destination location by using the GUI. During the user study the GUI was presented on a touch screen kiosk display connected to a laptop, which ran the application. The kiosk display is intended as an initial point of reference for visitors requiring navigation assistance, which can be further supplemented, for example, by a mobile phone and/or fixed displays.

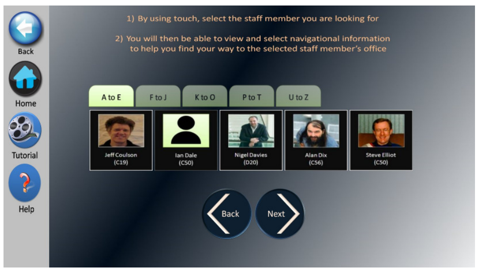

Figure 3. The Hermes2 Navigation System GUI

The GUI (see figure 3) enables 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. For assistance en-route users can "take away" and view the map and 3D route visualization by using a mobile phone. Furthermore, the GUI enables users to request graphical directional arrows on fixed displays. Details of the content and interactions are discussed in the forthcoming sub-sections.

Digital 2D Map Development

The digital 2D maps (see figure 4) were designed to provide participants in the user study with an overview of their route from their current location to their destination. The maps are modifications of architectural floor plans of the Infolab21 building, which at present only supports visitors through static on-the-wall signage. Modifications include 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 are presented on the GUI one floor at a time, that is, the subsequent floor is viewed by pressing a "show next step" button. The digital maps are essentially JPG images and their presentation on the kiosk display is static. However, interactivity can be introduced by viewing the map on a mobile phone and zooming in and out. As the maps are architectural floor plans, they are not designed to support visitors to the building and, therefore, we anticipated some limitations in the user study.

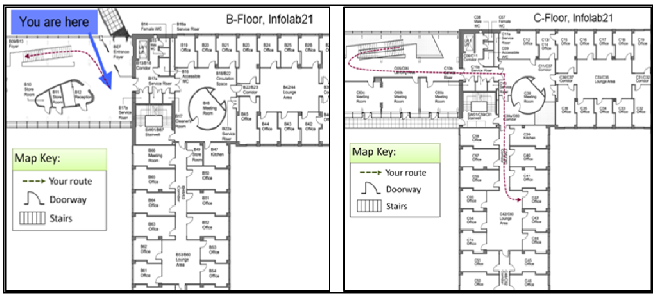

Figure 4. Examples of digital 2D maps that were shown during the user study

3D Route Visualizations

The 3D route visualizations were designed to provide study participants with a first person view of the route from their current location to their destination. The visualizations are presented as continuous media, that is, video clips of approximately 20 seconds (depending on the length of the route).

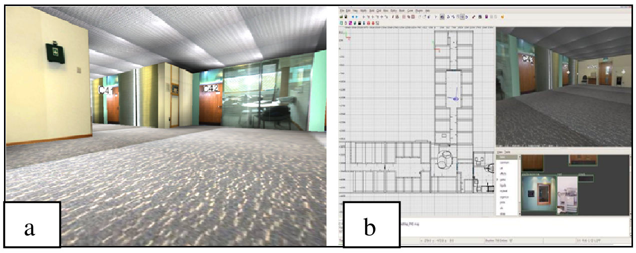

Figure 5. (a) Screenshot from the 3D route visualization (b) GtkRadiant development environment

A 3D model of the environment was developed using an open-source map modeling toolkit known as GtkRadiant (see figure 5b). The modeled map was then rendered using the Quake 3 game engine. GtkRadiant was used due to its open-source implementation, thus allowing flexibility in terms of bug-fixes, modifications and so forth. The model was constructed by creating 3D polygon structures, followed by applying photographic textures (e.g. photographs of the carpeting, ceiling, etc. were used). The photographic textures allowed the environment to appear photo-realistic and thus, salient in terms of color, form and appearance (see figure 5a). To augment navigation, office door numbers were enlarged so that they were clearly identifiable. The 3D route visualization video clips were generated by using a recording program (Fraps) to capture the Quake 3 character walking from one location to another (e.g. from the reception area next to the entrance to a lecturer's office). Thus, the speed of the video clips was determined by the default walking speed of the Quake 3 character. The clips were then converted into flash video files (.flv) to display on the kiosk display GUI and also on a mobile phone during the user study.

Graphical Directional Signage

The graphical directional arrows enabled us to explore whether users find this form of support useful whilst en-route to a destination location. The Hermes2 Navigation System GUI enables users to request this form of support. Once a staff member is selected on the GUI, the location is compared on a lookup table stored in the Hermes2 server and graphical arrows are shown on the Hermes2 displays that precede the destination. The GUI shows what the user's arrow will look like, and also displays an example photograph of a fixed display unit showing an arrow in order to inform the user about the type of display to expect. During the user study the arrows appeared immediately upon request and remained until participants located the destination office. The appearance of the arrows was designed to be semi-transparent in order to meet display owner feedback received in [9].

Use of Mobile Phones

As we are interested in how users view navigation content en-route on a mobile phone, and also whether they find this useful, the Hermes2 Navigation System GUI enables users to "take away" navigation content which has been viewed on the kiosk display.

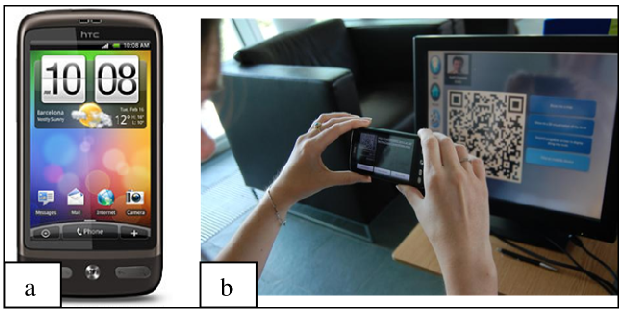

Figure 6. (a) HTC Desire mobile phone used during the study (b) Example of a user scanning a barcode

The GUI displays a barcode (figure 6b) generated using a barcode generator on the web[1], which can be scanned by an off-the-shelf open source barcode scanner application[2] on

[1] http://qrcode.kaywa.com/

[2] http://code.google.com/p/zxing/

the mobile phone (figure 6a). 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.

STUDY APPROACH

The methodology employed in our 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, for instance, was generally quite low. Furthermore, we did not receive significant feedback pertaining to the combined use of mobile and fixed displays.

The prototype Hermes2 Navigation System used in the formative study was set up by means of a kiosk display connected to a laptop which ran the application and displayed the GUI. The kiosk display was set up next to entrance to the building where the system is originally intended to be used. Ecological validity was maintained by recruiting participants who were unfamiliar with the environment. This was done by placing flyers in the Lancaster University campus to advertise the study.

Figure 7. Participant walking to her destination using a phone

Procedure

Prior to the study, participants were e-mailed with details pertaining to the procedure (e.g. the study purpose, anonymity of data, etc.). During the study, participants were given two task sheets with seven different instructions. The first set of instructions was designed to allow participants to become familiar with the system. They were asked to select a given lecturer on the kiosk display in order to view navigation content. Participants viewed map-based directions to the destination office, followed by the 3D route visualization. Participants were also allowed to become familiar with requesting graphical arrows en-route and with viewing the map and route visualization on the mobile phone. The supplied mobile phone was already connected to the internet via 3G; hence participants were not required to pay for connection costs. They were asked 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 second set of instructions was similar to the first; however, participants were required to physically locate (i.e. walk to) the lecturer's office using a mobile phone and furthermore, they were instructed to expect fixed displays showing graphical arrows en-route. They 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 (figure 8). We used an instruction-based procedure as the limited instructions given to participants in our previous studies caused shortcomings. The task sheets also ensured that all participants were exposed to both the digital 2D maps and the 3D route visualization. The length of each session was between forty-five minutes and one hour.

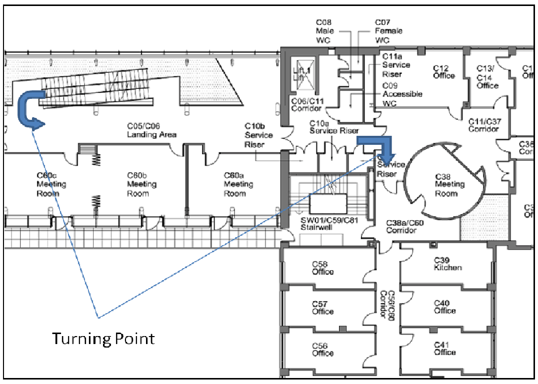

Figure 8. The two turns that participants undertook en-route

Evaluation Methods

Evaluation methods included protocol analysis, observation, semi-structured interviews and questionnaires. A Dictaphone, which was used to record the entire session with each participant, enabled us to capture protocol analysis data. A video camera was used to record participants whilst they were searching for the lecturer's office, thus enabling us to observe interaction with the mobile phone and the physical environment.

RESULTS

Participant Demographics

The formative study included 16 participants (9 male, 7 female) with an average age of 24.3 years. In terms of computer literacy, six participants had above average literacy, eight participants had average literacy and two participants had some knowledge. Nine participants considered themselves as having good spatial awareness, two participants as having average spatial awareness and five participants as having difficulty with spatial awareness. Nine participants generally liked using traditional maps, two were indifferent and five participants disliked using maps. Fifteen participants had no experience of the building and one participant had once been to the café.

User Preferences for Navigation Content

Fourteen out of 16 participants chose to view only the 3D route visualization and two participants viewed only the map on the mobile phone. Seven participants 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 two 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 content viewed on the mobile phone and general attitudes toward using traditional maps (or their self-perception of spatial awareness). 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.

Considerations for Digital 2D 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 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 [20]. In contrast, five participants 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.

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 out of 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 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 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 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".

User Preferences for Fixed 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 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 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 reinforced and carried on to successfully locate their destination. Seven out of sixteen participants however, did not notice the displays, mainly due to being fixated on navigation content 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.

Considerations for Display Placement
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).

User Preferences for a Combination of Technologies
In order for a combination of a mobile phone and fixed displays to be used effectively, we explored the types of interaction that study participants would prefer. In terms of viewing both a digital 2D map and 3D route visualization on a mobile phone, eleven participants confirmed that it was essential to be able to switch between the two

effectively. 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.

Switching between navigation content can also mitigate limitations caused by one type of content. Three 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 seven out of sixteen 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 navigation content displayed on the phone.

Indoor Navigation using a Mobile Phone

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 protocol analysis showed that all participants had an understanding of the directions to the destination location after viewing navigation content on the kiosk display and furthermore, 12 out of 16 participants confirmed that they had a rough idea of their route before setting off. However, the protocol analysis 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 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…"

The reason for pausing at decision points is related to the participants' unfamiliarity with the environment and although it appeared they had an understanding of the route, by following a guide (i.e. the mobile phone) the decision to turn was not executed by the participant herself; the decision was executed for the participant by the navigation content on the mobile phone. Arthur and Passini stated that "it is easier for people to remember a route if the wayfinding decisions are made by the user rather than following a guide" [1].

Our study also showed that participants were predominantly fixated on the mobile phone for receiving navigation support, 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.

Overall System Use

The attitude of study participants was generally positive (see figure 9) in terms of the overall system, i.e. using a combination of a kiosk display, mobile phone and Hermes2 digital displays to view navigation content. All 16 participants were successful when asked to walk to and locate the destination office, and only one participant had a significant amount of difficulty.

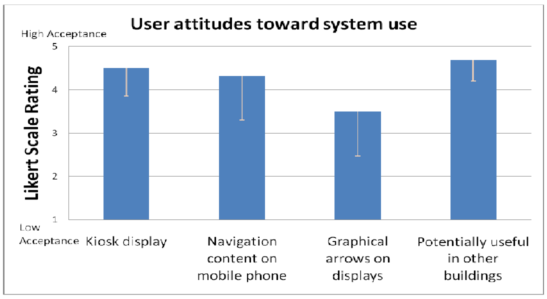

Figure 9 – Likert scale ratings on overall system use

The Likert rating for the digital displays was slightly lower compared to other categories, mainly due to the fact that some participants noticed the displays whereas others were fixated on the mobile phone whilst navigating to the destination location. In addition, due to this a higher standard deviation value was produced (1.03, 2 s.f.). The standard deviation value regarding mobile phone use also showed a higher spread (1.01, 2 s.f.) as one participant had issues playing the 3D route visualization along her route.

DISCUSSION AND FUTURE WORK

The formative study enabled us to form an in-depth understanding of user preferences for: (a) customizing and combining navigation content and (b) combining the use of mobile and fixed displays.

Study participants suggested various forms of controls for customizing navigation content on a mobile phone. Some of these include the ability to control the playback speed of the 3D route visualization (e.g. by using a slider bar) and also a tracking feature (e.g. similar to a satellite navigation system) for the digital 2D map. It was evident that the requirement of customization and control of navigation content was essential on the mobile phone in comparison to a fixed display. In more detail, participants did not suggest any preferences for receiving support on the kiosk display. In [25], designers of Nokia phones state that "…the personalization of the mobile phone may play an important role: The constant use of the mobile handset becomes a very personal object…" This is especially an important factor as participants were reliant on the phone rather than their own sense of direction (especially as 12 out of 16 participants commented that they already had a rough idea of their route).

Participants also suggested a means of switching between the digital 2D map and 3D route visualization by, for instance, a graphical button placed at a corner, viewing the 3D route visualization from a specific position on the digital map, and so forth. This would allow users to mitigate difficulties faced with one type of navigation content. Three participants, for instance, stated that if the environment presented in the 3D route visualization did not correspond to the physical environment, it would be beneficial to switch to the digital 2D map (which presents an overview of the environment).

The graphical arrows shown on the Hermes2 digital displays were useful in reassuring study participants that they were walking in the correct direction. Two participants in particular, who were unsure of their current location, viewed the graphical arrows on the displays and felt reassured that they were in the correct location. Similarly, the feeling of reassurance and reinforcement was shared by participants who viewed the graphical arrows simply as an additional form of information whilst navigating using the mobile phone (i.e. participants who were not facing difficulty in finding the destination). The study showed that seven out of sixteen participants were fixated on the mobile phone and did not notice the displays, despite being informed of them on the kiosk display and the task sheet. This finding is also shared by Muller et al's study in [13], where the authors found that users navigating with a mobile phone would only interact with public displays when disoriented. Participants also suggested that it would be useful to view the graphical directional arrows earlier in the route, such as from the beginning or at decision points (i.e. where users need to make a turn).

Our findings demonstrate that the components of the prototype Hermes2 Navigation System were able to effectively support the study participants in finding their way to the destination location. We aim to follow up on the feedback provided by participants regarding the types of interactions preferred for receiving indoor navigation support in order to design the next formative study. Furthermore, the next step will involve investigating how mobile and fixed display systems would provide support for multiple users. This will enable us to explore the utility of such a system in more demanding environments, such as hospitals.

CONCLUSIONS

In this paper we have investigated user preferences for indoor navigation support using a combination of mobile and fixed displays. A formative user study was carried out using the Hermes2 Navigation System, which consists of an experimental set-up of Hermes2 displays, mobile phones and content such as 3D route visualizations, digital 2D maps and graphical directional arrows. Results from the study have addressed the research questions outlined in the Introduction and provided insights to the supporting components required for the development of an interactive indoor navigation system. Below we describe conclusions that contribute to the research pertaining to user preferences for indoor navigation support.

- It was evident that the need for customization and control was higher when participants interacted with a mobile phone in comparison to a fixed display system such as the kiosk display. It was clear, for instance, 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 fixed display configurations (i.e. areas without displays that would show navigation content such as graphical arrows).
- It is essential to consider the accuracy of navigation information provided on a mobile device as our study showed that 12 out of 16 participants had a tendency to rely on the device rather than their sense of direction (especially as 12 participants stated that they already had a rough idea of the route before walking to their destination).
- 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 whilst using a mobile phone, (b) when facing difficulty using a mobile phone, and (c) as an opportunistic information source.
- It was apparent that when mobile and fixed displays are used to support navigation, users are likely to be fixated on a mobile phone despite being aware that fixed displays are showing digital signage. Seven participants in our study, for instance, did not notice the displays whilst navigating with a mobile phone.

Our study demonstrated that participants were very positive towards the prototype Hermes2 Navigation System. Furthermore, the study enabled us to form a greater understanding of the different types of user preferences for an indoor navigation system.

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