Exploring factors that influence the combined use of mobile devices and public displays for pedestrian navigation

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ABSTRACT

Large displays are rapidly proliferating in public spaces, and could therefore be an attractive resource to support nomadic users in such contexts, e. g. by providing additional screen real estate or by augmenting services delivered through a mobile device. While previous work on combining public displays and mobile devices has identified a number of benefits of this combination, it is not yet clear if users will actually use such a system and if they do, why and when. In this paper, we present two initial user studies investigating factors relevant to user acceptance and usability in the context of a deployed system that provides pedestrian navigation support through a combination of mobile devices and public displays. Based on the results from a repertory grid analysis, we identify dimensions that are relevant for users deciding whether to use a public display or not, and discuss implications for the design of such systems.

Categories and Subject Descriptors

H.5.2 [**Information Interfaces and Presentation**]: User Interfaces—*input devices and strategies, interaction styles*

General Terms

Design, Human Factors

Keywords

mobile phones, public displays, navigation support, user study

1. INTRODUCTION

Comparing today's mobile devices (e. g. mobile phones, PDAs, media players) to those of a few years ago, there is an obvious trend towards smaller devices while at the same time battery life as well as networking and computational capabilities have been considerably improved. Simultaneously, several properties of the displays used in mobile devices keep getting better, e. g. resolution, colour, power requirements or readability. However, due to shrinking device sizes there is an inherent limit in terms of how big those displays can be.

Depending on the application being used on mobile devices, this small screen size can be a considerable usability problem. Typical examples for such applications include web browsing, and the exploration of large documents such as spreadsheets, long text files, or maps. Several approaches have been proposed in the past to overcome this issue such as novel visualisation techniques and hardware innovations (e. g. nano-projectors or foldable displays).

In this paper we explore an alternative approach to increase the screen real estate available to nomadic users: the combined use of mobile devices and public displays. Since large displays are rapidly being deployed in many public places such as shopping malls, airports and city centres, it makes sense to investigate their use by mobile users. However, using a public display is quite different from using a display embedded in a personal device, for example with respect to interaction, privacy or variations in viewing distance. It is not yet well understood, which aspects are relevant in such a scenario, and what their impact is on the combined use of mobile devices and public displays. The goal of the work presented here is to identify relevant factors in this context through a user study with a deployed system.

In the remainder of this paper, we first discuss related work in section 2. We then introduce the MobiDiC Shopfinder system, that provides navigation support through mobile devices and public displays (section 3). The system was evaluated by a first user study which is shortly described in section 4. This system enabled us to conduct a user study investigating the aspects mentioned above that we describe in section 5. We then discuss the potential implications of the results we obtained for the design of such systems (section 6). The paper concludes by summarising our contributions and giving a brief outlook on future work.

2. RELATED WORK

A key motivation for using public displays in conjunction with mobile phones is to increase the screen real estate available to the nomadic user. In the past, this issue has often been tackled using a variety of visualisation techniques, which compensate (to some degree) for the lack of screen size but which cannot overcome the physical size limitations. Examples for such techniques include Halos [2], which provide peripheral cues towards the location of off-screen objects, DateLens [3], which applies a fisheye metaphor to a calendar, and AutoZoom/GestureZoom [18], which uses speed-dependent zooming to optimise image browsing on small screens. Unlike such techniques, using a public display yields a net increase of the available screen size.

Research on public and situated displays has investigated a wide range of issues, including applications, interaction and collaboration (see [17] for an overview). In the context of this paper, the joint use of mobile devices and public displays is the most relevant area of research. Ballagas et al. [1] presented an in-depth analysis of smart phones as a generic input device. The C-Blink system [16] is an example for a mechanism relying on purely visual interaction – no network-connection is required. Instead, an external camera is used to track a mobile phone that is displaying a sequence of colours. The Digital Graffiti system [5] enables nomadic users to annotate content displayed on a public screen, which relies on sending data from a mobile device over a network connection to a public display. Users of this system can use a PDA to create notes relating to content shown on the public display, which are then shown alongside the content on the public screen. During their initial field experiment at a conference, the authors observed that after a brief phase of joint use, users would rely solely on the mobile device and not return to the public display. They partially attributed this to the display not being located in the main conference room. This is one aspect that we are aiming to investigate in the context of the study presented in section 5. The Bluetooth Photo Display [6] also relies on a (Bluetooth) network connection to combine mobile devices and public displays but enables direct interaction with the content of the public screen. Once connected, users can use the keyboard of their mobile phone to control a cursor on the public display in order to select an image they wish to download. Images are posted and downloaded via Bluetooth as well.

In our user studies we use a system providing navigation support through mobile devices and public displays. There are some existing systems, which provide similar services. Kray et al. [13] built a system relying on public displays alone. The public screens in this system are location-aware and receive generic presentations and adaptation rules describing routes, which enable them to compute and display directions that are appropriate for their location. The rotating compass [20] tightly integrates mobile devices and public displays, which show a rotating arrow. In order to convey the direction users have to take, their mobile phone vibrates whenever the arrow points in this particular direction. Lijding et al. have proposed the Smart Signs system [14], which provides a number of services in addition to navigation support through dynamic door plate displays. Users wear a tag that they use to identify themselves to the smart sign displays.

The particular design we use builds on the work of Beeharee et al. [4] which combines maps with landmark photos and textual instructions on a mobile device. Beeharee et al. show that the availability of landmark photos can increase navigation performance. In their experiments, users used the map mainly at the start of a route and when lost, while they used the landmark photos mainly to confirm that they made the right decision. Beeharee et al. state that the small size of the screen was a major problem while reading the map and especially hampered the recovery to the designated route when lost. This problem provides the opportunity to combine both the strengths of public displays and mobile devices. The map needs a lot of screen real estate but is not needed continuously, therefore it can possibly be provided on public displays. The landmark photos can be viewed well on a mobile devices and are needed continuously to confirm decisions, therefore they can be provided well on a mobile device.

Our system differs from previous systems in several ways. In particular, it has been deployed both indoors and outdoors, whereas the majority of previous systems has only been used inside buildings. Another key difference is that in our system the use of either the mobile device or the public displays is optional; wayfinding is possible using the mobile device alone, using only the public display or using a combination of both. This particular design facilitates the investigation of the question if people will use mobile devices and public displays together, and if so, when and how. It is not yet clear which factors influence usability and user behavior in the context of mobile device-public display combinations. A variety of factors have been proposed in the literature, among them privacy [7], [20], visibility [9], control [12], means of interaction [21] and technical factors [6]. However, most of these factors have been derived in an ad hoc manner, and their relative importance has not yet been investigated. The goal of the work reported in this paper is to systematically gather relevant factors through user studies, and to gain an initial understanding of their importance.

3. THE SHOPFINDER SYSTEM

MobiDiC Shopfinder is a navigation system for Münster combining mobile phones and public displays, which we used in our investigations reported in the following sections. It was deployed during a project aimed at delivering localized advertisements, and currently consists of 20 public displays that are integrated in public phones in the city center. The screens usually display advertisements and coupons for local shops. The system also provides a small guide application that people can download to their mobile phone in case they do not know the way to a particular shop. The application provides guidance by showing a series of landmark photos for each decision point on the route (see Figure 1) that are annotated with route instructions. Since a user has to manually select a particular photo, no automatic positioning is needed. The application thus works with most mobile phones. Whenever a user passes a public display, it temporarily stops showing advertisements and instead displays an overview map with the individual route for this user (see Figure 1). When the user leaves the display, the normal advertising schedule is resumed.

The MobiDiC Shopfinder has been designed according to requirements elicited in a questionnaire with 39 shops in the city center as well as in interviews with 24 pedestrians. In order to download the guidance application, a user has to take a photo of the advertisement and to send it to the display via Bluetooth. The display then calculates the shortest route to the shop, annotates the landmark photos with route instructions, and builds a Java MIDlet specifically for this route. The MIDlet is then sent to the user's phone via Bluetooth. At the same time, the Bluetooth MAC address of the phone, the destination and a timestamp are stored on a central database server. The displays continuously scan their environment for Bluetooth devices, and check with the central database whether any Bluetooth MAC address they detect corresponds to a device that has downloaded the guide application within the last couple of hours. If a device is found, a new route from the current display to the user's destination is computed, and a corresponding overview map is generated and then displayed on the screen.

The system has been deployed in public for six months. At the moment, the current version does not display overview maps as the displays have not yet been equipped with a continuous network connection. For the studies reported in the following section, we therefore temporarily enabled this feature. During the deployment, we have registered 130 downloads of the guide application by 'real' users.

Figure 1: MobiDiC Shopfinder: Guidance application on the mobile phone (left) and overview map on public display (right).

4. FIRST USER STUDY

After deploying the Shopfinder in public, we conducted an initial field study to investigate how users would use the public displays and whether they perceive them as helpful.

4.1 Scenario

The route used for the study was located in the city center of Münster. It was 350 m long and consisted of six decision points. There was one particularly difficult decision point, where street signs were confusing. Three 13" public displays were located next to each other about 10m away from this decision point.

4.2 Method

We recruited 14 users aged 21 to 29 years, five of them female, nine male. We used a between subjects design where seven users were provided with the mobile phone alone, while seven users additionally had access to overview maps on the public screens. The route started at a public display that did not provide an overview map, just to make users familiar with the displays. Users were handed out a Nokia N70 mobile phone with the navigation software already started. While the users completed the route, we followed a few meters behind, to both measure the time and count the errors. When users walked a few meters in the wrong direction, an error was counted and they were set back to the route. After they completed the route, we went through a short semi-structured interview with them, in order to investigate whether they perceived the mobile device and the public displays as helpful.

4.3 Results

Those users who actually used the public display perceived it as very helpful. One participant lost his way right next to the displays and started looking for them. When he spotted them, he immediately approached them and looked at a display for nearly one minute. In the interview, this user stated: *'I felt lost all the time, and did not know if I am right or completely wrong. Then I saw that display and got an overview over the route. [...] Then I had the feeling to know the right way.'* After looking at the display, the user confidently walked in the right direction and reached the goal without further errors. Another user was confused at the difficult decision point and stopped, looking around. After searching the environment for about half a minute, she saw the display to her right and approached it. She looked at the display for about one minute, and then headed in the right direction, completing the route without further errors.

Interestingly however, many users did not notice the displays at all. Although all seven users in the display condition were confused at the difficult decision point, and four of them walked in the wrong direction at that point, only two participants used them. Even though the displays were located within a few meters from this location, most users looked at the phone or repeatedly scanned the environment, apparently without noticing the public displays. When asked why they had not looked at the public displays, two of them stated that they forgot to, and three insisted that they had not seen any. One user stated *'I looked at the phone and the environment the whole time, and I just forgot to look for displays'*.

4.4 Discussion

It is promising that the users who actually used the public displays perceived them as very helpful. With only two users actually using them however, it was clear that more work was required to find out why people do (not) use public displays. Based on user feedback and observations during the experiment, there were a number of potential reasons why only few users used the displays. Firstly, most users were quite busy looking at their mobile phones and looking for the landmarks in the environment. It is quite possible that this caused such a high workload that users simply were too busy to search for public displays. This might also be a result of the specific method of navigation (landmark photos), which might have caused the users to selectively pay attention to landmarks only and ignore public displays. Moreover, switching focus between the mobile phone and a public display can be demanding in itself. In summary, the study indicates that public displays can be perceived as helpful in navigation, but it is not yet clear which factors influence whether users actually use them.

5. SECOND USER STUDY

Based on the results obtained in the initial user study, we decided to further investigate which factors influence the decision of users whether or not to use a public display. In the literature, a number of factors have been discussed but often, they are derived in an ad hoc manner, and it is difficult to judge the relative importance of the different factors. We therefore designed a second user study to research those factors in more detail.

5.1 Design

As a first step towards a classification of relevant factors, we wanted to learn what users themselves thought were factors influencing their use of public displays. In order to collect this information, we decided to conduct repertory grid interviews. Repertory grid interviews [11] have been employed for many decades to elicit the dimensions (constructs) that users use to think about (construe) a certain domain. In repertory grid interviews, users are presented with a number of elements in groups of three. In our case, the elements were the concrete situations where the user approached a certain display, as the users perceived the situations themselves. For each selection of three situations, they are asked to state which two of them have something in common that is different from the third situation. They then have to describe what the two have in common (emergent pole) and how the third one is different (implicit pole). These poles could be for example *'I am currently looking at the phone'* versus *'I am currently looking for landmarks'*. After providing a description, they are asked to rate each situation on a (5-point) Likert Scale. This process is repeated until no more constructs arise. The result from each interview with a user is then a number of constructs, together with the rating of the provided situations for each construct. This collection of constructs and ratings is called a repertory grid. To evaluate the grids we chose to apply Honey's content analysis [8], as it enabled us to analyse data from multiple grids (one from each user) and to compare the importance of different constructs by measuring the correlation between the constructs rating and the rating of a supplied overall construct (see section 5.3). This correlation (% similarity score) can be categorized for each grid into high (H), intermediate (I) and low (L) correlations, to improve comparability between different grids. The elicited constructs are then categorized using affinity analysis, and for each category a mean % similarity score can be computed. This score can be used together with the number of constructs in that category and the HIL values to estimate the relative importance of that category.

We let users experience eight different situations where they could use public displays for navigation. Afterwards, we conducted the repertory grid interviews, where users compared the different situations and identified the factors, or constructs, which they believed to have influenced whether they used the displays or not.

5.2 Scenario

In order to create a variety of different navigation situations, we had users navigate both indoors and outdoors. For the outdoor scenario we used displays that were installed in public telephones; for the indoor scenario we used displays that were installed as part of a university information system. Thus we had no possibility to influence the actual location of the displays. Table 1 lists the locations of the displays. The outdoor display locations are named o1 to o3, the indoor locations i1 to i5. The # column indicates, how many displays were situated on the particular location. The angle was measured between the display surface normal and walking direction ('-' refers displays at start locations). So, 180° means the user is heading directly to the display, while at 20° he has to turn his head. The next columns state screen size, the mean number of bystanders and a textual description of the environment. The route of the outdoor scenario was 600 m long and had four major decision points while the indoor route was 120 m long and had six decision points. An impression of location o1 is shown in figure 3 and one of location i5 in figure 2.

Table 1: Setup of locations with number of displays per location, angle to walking direction, screen size, mean number of bystanders and a short description

Name	#	Angle	Size	Bystanders	Description
o1	4	-	13"	few	post office
o2	3	180°	13"	many	train station
o3	1	90°	13"	few	bus stop
i1	1	-	42"	many	coffee room
i2	1	20°	24"	few	foyer
i3	1	90°	19"	few	hallway
i4	1	90°	42"	few	main entrance
i5	1	180°	42"	many	seating area

Pretests had shown that the Bluetooth scanner introduced a delay that resulted in the system displaying the map at a time, when many users had already moved on from the display. We therefore configured the displays in the outdoor condition to display the maps continuously. For the indoor condition, we used a Wizard of Oz approach: the wizard observed what happens through cameras installed on top of the displays, and manually changed the display content from a control console. Displays were switched to displaying the map after about one second after a user had approached the displays. In order to investigate whether users would be irritated by bystanders, we placed two persons in the sofa corner, who we instructed to chat about topics unrelated to the research.

Through this setup, we were able to vary the number of people around, the kind of people around, the size and angle of displays, the density of displays and indoor/outdoor. Additionally, we wanted to investigate whether the type of the destination would have any impact. Every user hence had to navigate to two different destinations: a public toilet and a café/the coffee room. Furthermore, we were interested whether obfuscation of the user's goal would even out difference between different types of destination. Thus, some displays showed multiple routes, while some only showed a single route. Finally, in order to gain an insight into the impact of different delivery methods, we created two versions of the navigation software on the mobile phone. One version provided guidance through annotated photos of landmarks (landmark condition); the other version displayed a subsection of the map shown on the displays (map condition). The location of all public displays was always annotated on the maps shown on the public displays. In addition, in the map condition the location of the displays was also shown on the mobile phone, while in the landmark condition the location of the displays was not available from the mobile phone.

Figure 2: User looking at display i5 during experiment 2, while two bystanders chat about unrelated topics.

5.3 Procedure

We recruited 11 users, aged 23 to 26 years. Five users were female, six were male. All users knew the area around the train station, but had not visited the office building before. All users completed the outdoor route first, and the indoor route on the next day. All other factors that we could control were varied among the situations, while taking care that two conditions did not vary simultaneously. At the start of the experiment, operating instructions for the software were read to the users. Then they were shown the first public display and the mobile phone was given to them. While they were navigating, we followed at a distance of a few meters, taking a video of the whole route. When the users walked a couple of meters in the wrong direction, they were set back to the correct route.

In order to enable users to reflect why they had ignored displays, the users were shown all displays that they missed after completing the route. After the second route, the users were interviewed using the repertory grid technique. The method was shortly explained to the users. We provided them with three situations and asked them what two of them had in common as opposed to the third in terms of why they had or had not used the displays. The answer, the emergent pole of the construct, was written down. In order to obtain the implicit pole of the construct, we asked the user what property of the other situation made it different from the other two. We then asked users to rate each situation on a 5-point scale where the emergent pole would be 1 and the implicit pole would be 5. This technique was repeated until users became stuck with the same constructs, which usually happened after about eight constructs.

We then showed users the video footage of themselves completing the two routes. We asked users to explain what they had done at every moment and why. Long periods without displays were skipped. We then continued the repertory grid interview to see whether any new constructs emerged. When users could not find any new constructs, we asked them to rate the provided construct *'I would always use the display in this situation'* versus *'I would never use the display in this situation'* (overall construct). In total, we elicited 97 constructs.

We analyzed the repertory grids using Honey's content analysis technique [8]. First we computed the sums of differences and % similarity scores for each construct against the overall construct (a measure for the correlation of the two ratings). We then equally grouped these % similarity scores for each interview into high (H), intermediate (I) and low (L) scores. In an affinity analysis [11], two raters independently grouped the constructs into categories. The categories that emerged were sufficiently similar, with a satisfactory cross rater reliability of 61.63% before and 94.84% after the harmonization of the categories. We chose examples of each category as those constructs with highest % similarity scores that represented the different subcategories well.

Figure 3: User (left) looking at the map to the toilet on a display while a bystander is making a call in front of another display at that location (display o1).

Table 2: Number of seconds that users looked at displays o1 to i5. In addition, the mean number of focus changes between each display and the phone (Fix.) are given. The video tapes of one participant could not be accessed after the interviews.

Disp.	**o1**	**o2**	**o3**	**i1**	**i2**	**i3**	**i4**	**i5**
Fix.	3,2	1,33	1	1,6	2	1,17	1	1,3
User								
u1	31	0	0	7	17	3	1	3
u2	10	5	0	20	0	3	0	4
u3	7	0	0	5	0	12	0	4
u4	23	1	1	6	0	0	0	3
u5	48	8	5	10	9	21	0	6
u6	15	0	0	13	0	6	2	4
u7	45	0	0	7	0	0	0	1
u8	12	1	0	7	0	0	6	2
u9	7	5	23	3	10	7	0	3
u10	13	2	0	3	0	0	0	0

5.4 Results

The time that participants spent looking at the displays (viewing time) is shown in table 2. Users often looked back and forth between the display and the mobile phone; the table shows the accumulated viewing time for each display. The times varied considerably between displays, indicating that different displays have been used for different purposes.

Table 3: **Categories of constructs from the Repertory Grid analysis in order of importance. Constructs were categorized in an affinity analysis. The category name, exemplary constructs, number of constructs (n), mean % similarity scores, and High-Intermediate-Low ratings of constructs are mentioned for each category.**

Category	Constructs	n	mean %sim.	H-I -L
Next landmark visible	I can already see the next goal - I can not yet see the next goal (75%sim.,H) At the goal - Overview [2] (68.75%sim.,H)	5	58,75	4H 1L
Focus mobile phone or environment	I am currently looking at the phone - I am currently looking for landmarks (68.75%sim,H)	4	57,81	2H 1I 1L
Orientation or confirmation	Overview - Control, when you are uncertain (62%sim.,H) Orientation for new section - Within a section (75%sim.,I)	15	48,33	6H 7I 2L
Decision point	Decision point - Straight route (81.25%sim.,H) Change of direction - Keep straight on (68.75%sim.,H)	8	44,53	3H 5I
Visibility	Within field of vision - Out of field of vision (75%sim,H) Did not walk directly towards it - Did walk directly towards it (68.75%sim.,H) It is necessary to be hinted at the display - One does see it automatically (56.25%sim.,H) At eye height - Above eye height (25%sim.,L)	17	44,12	8H 5I 4L
Familiarity with environment	I have a representation of the way in my head - Uncertainty on the way (75%sim.,H) I feel lost - I know the way (62.5%sim.,H)	9	43,06	5H 2I 2L
Phone sufficient	Phone provides sufficient information - Phone provides too little information (50%sim.,I) I know where I am on the phone - I don't know where I am on the phone (56.25%sim.,H)	6	39,58	2H 2I 2L
Social Context and Privacy	I can look calmly - Bothered looking (50%sim.,H) One can stand in front well - I am blocking the way (31.25%sim.,I) Uncomfortable - Comfortable (31.25%sim.,L) Many people stand around - No people stand around (25%sim.,L)	4	34,38	1H 1I 2L
Map or Photo	Match mobile to screen - No match necessary (68.75%sim.,H) Map on the phone - Photos on the phone (25%sim.,I)	3	33,33	1H 1I 1L
Display as landmark	Display as landmark - Display not as landmark (56.25%sim.,H)	2	31,25	1H 1L
Expect display	I know where the next display is - I don't know where the next display is (50%sim.,I)	4	29,69	1I 3L
Display confusing	Not confusing by multiple lines - Confusing by multiple lines (18.75%sim.,I)	4	25	4I
Display density	Displays close to each other - Displays too far away from each other (31.25%sim.,I)	3	25	1I 2L
Whole route or section	Whole route shown - Only parts shown (25%sim.,L)	2	25	1I 1L
Display size	Big - Small (25%sim.,I)	6	21,88	2I 4L
Route complexity	Confusing - Simple route (12.5%sim.,L)	3	16,67	3L
Delay	Map is there immediately - Have to wait for map (18.75%sim.,I)	2	9,38	1I 1L

The categories of constructs that were elicited in the repertory grid interviews are summarized in table 3. The first column states a descriptive name of the category, as chosen by the authors. The second column lists a selection of constructs which are exemplary for this category. For example, the second user stated that displays o2 and o3 have in common that he could already see the next goal, while at display o1 he could not yet see the next goal. The rating of the individual displays for this user was to 75% similar to his rating whether he would use the displays or not. Thus, this construct was among the top third (H) of all constructs from this user. The next column states that this category has n=5 constructs, and the mean % similarity score for all constructs is 58.75%. In total, four of the constructs in this category were rated high, while one was rated low. In the following we provide more detailed descriptions of the observations regarding the categories with highest mean % similarity scores and refer to the tables where necessary.

Next landmark visible ($\mu = 58.75\% sim.$).

This category relates to the fact that users skipped a screen and directly headed for the next landmark in case it was already visible when the user approached the screen. Some displays were consistently skipped, in particular all users in the landmark condition skipped display o3, four of them skipped display o2, and display i4 was skipped by all except three participants from both conditions. In the interviews the users explained that they would skip a display and head for the next landmark when it was already visible when they passed the display. In case of display o3, all six users in the landmark condition chose a shortcut we had not anticipated and thus did not pass the display directly. Only one of five users in the map condition did so. In case of display i4, the next display was only a few meters away and already visible, so most subjects skipped ahead to display i5. Regarding displays o2 and o3, one user stated: *'When I would have needed them [the displays, annotation by the authors], I immediately saw the next landmark on the phone. So I saw the insurance shop. And I saw that one immediately, when I turned in, I don't quite remember the name of the street, Berliner Platz [display o2], I think. That was the same at the Wolbecker [display o3], because there I saw the bridge and the building.'* Some users also stated that they would not use displays o3 or i5 when they are sure to be close to the goal anyway.

Focus mobile phone or environment ($\mu = 57.81\% sim.$).

This category subsumes that in situations when users are busy looking at the mobile phone, they tend not to notice the displays. As in the first study, we observed that most users looked at the mobile phone quite intensely. Users often switched the focus between looking at the phone and looking around in the environment, apparently trying to match the information from the phone to the environment. In the interview, one user stated *'I was so focused to the phone, and tried to find the way with the phone, that the displays were generally rather secondary'*. Another user described the situation at display i3 in the following way:*[Interviewer]: 'So you didn't notice that there is a display at all?' [User]: 'No, because I looked at the phone all the time [...] When I was sure from the phone, where I have to go, then sometimes I looked up. But then I rather paid attention to room numbers* *or what's next on my way. [...]' [Interviewer]: 'How does that influence whether you look at the displays?' [User]: 'If there would have been a display right then, of course I would have seen it. But probably I looked right then when there has not been any.' [Interviewer]: 'Did that happen, that you looked up and then there was a display?' [User]: 'Yes, at the elevator [display i4]. And then I used it'.* Interestingly, from the video footage it seems quite obvious, that the user was confused at that point and looked intensely at the phone. So she first passed display i4 without noticing it, then apparently saw the display annotated on the phone, then turned around laughing and looked the display for 6 seconds. A very similar situation could be observed with another user in front of display i2.

Orientation or confirmation ($\mu = 48.33\% sim.$).

This category encapsulates the fact that the first displays in certain sections of the route were used quite differently from the subsequent displays. Users looked at the first displays for quite a long time, while they only glimpsed briefly at subsequent displays. According to a paired one-tailed t-test, Display o1 has been used significantly longer than displays o2 ($\alpha = .0016$) and o3 ($\alpha = .0056$). Display i1 has been used longer than Display i2 and i3 (not significant), and longer than display i4 ($\alpha = .001$) and i5 ($\alpha = .002$). Most users looked at the first displays for a fairly long time, and then started to look at the phone and back at the screen, alternating about two or three times (see table 2). The displays along the route were used much less. Users mentioned that it was either sufficient for them to see that there was a map at all, or to see that there was a dot (the current position) in front of the display so they could see that they are on the right way. In the interview, one user described the situation at display o1 as: *'I tried to learn the route roughly and looked at the photos, if I know the buildings and find them then.' [Interviewer]: 'Did you look at all the photos?' [User]: 'Yes, I looked at all of them right away.'* Another user said:*'Of course I used the first one [display o1] quite a lot, because it gave a broad overview. So I find that one relatively important. And the others I did not use at all this time. Maybe they are not bad, if you are uncertain about the way.'* Yet another user stated *'So I looked at the post office [display o1], where do I have to walk? And at both others I just looked if I am on the right way'.*

Decision point ($\mu = 45.54\% sim.$).

This category describes whether a display was located at a decision point. Displays at decision points or where users had to change direction were stated to be used more than displays where users had to go straight ahead. Displays o3, i3 and i5 for example where located at places where users had to change direction. One participant made the following example comment in this category. *[User]: 'For one [display i3] it is a corner for sure. And if it is a corner, I always used it more.' [Interviewer]: 'Really? For what reason?' [User]: 'Because I had to change direction. And if I have to change direction, I would use it more than if not.'*

Visibility ($\mu = 44.12\% sim.$).

This category encompasses different aspects that influence how visible a display is to users. Regarding display o2, one user stated: *'I walked directly towards it, it immediately caught my eye.'* Display i2 was around the corner from the users walking direction, and users would have to turn around to see it. Only three users even noticed this display, and one user stated: *'So that one was not important for me. It was back there on the wall, [it] was rather somewhat inconspicuous'.* Display i4 was placed in a similar situation. When the users walked around the corner, it was at their left, at eye height, about 20cm from their face. Even though it was large 42" LCD screen, only a very small number of users noticed it at all.

Familiarity with environment ($\mu = 43.06\% sim.$).

This category relates to how confident users are that they are on the right way. Some users knew the region around the train station well and therefore made only few errors. The office building on the other hand was new to everybody, so more errors happened. Users stated that they would prefer to use the phone as opposed to the display, when they know the way: *[User]: 'I already had an image of the way in my head.' [Interviewer]: 'Does that influence whether you look at the displays?' [User]: 'Yes, exactly, when I am already walking and just take the phone, just to check, then I don't have to stop to look more closely to one screen.'*

Phone sufficient ($\mu = 39.58\% sim.$).

This category describes whether the phone provides sufficient information in the current situation. One user explained this as *'Probably the phone didn't provide me new clues in the elevatorthing, therefore I just used the display again. [...] So I virtually used the display as a supplement to the phone information.'* Another user referred to this aspect in the following way: *[Interviewer]: 'So on the fifth floor you did not look [at the displays]' [User]: 'Yes. Did not pay attention.' [Interviewer]: 'Why didn't you pay attention?' [User]: 'Yes, because from the phone I was still confident, that it's right. There I had the information I need.'*

Social Context and Privacy ($\mu = 34.48\% sim.$).

This category describes how comfortable users were with the situation, e. g. whether they were interfering with other people or vice versa. During the experiment, some bystanders were standing right in front of the display (e. g. in figure 3). Especially for the displays at the train station and the sofa corner, bystanders were around continuously. One user mentioned, that when he passed display i2, some students were playing tabletop football next to it, so he did not look at the display in order not to stand in their way. One user stated *'I could stand in front [of display i1] really well.'*. She contrasted this with *'That was the same [as display i3] at the elevator [display i4], I stood kind of in the passage. And somehow that was so cramped'.* Interestingly, not a single user mentioned any concerns about relaying their destination to strangers via the public display, neither for the toilet nor for the café.

Further categories.

The category *'Display as Landmark'* captures the fact that some participants used displays as landmarks in their own right. In particular, subjects in the map condition tended to behave in this way. However, this does not mean that they read the actual content of the screen. One user stated: *'I believe it was indoor, because it [the display] was just a kind of landmark. And that is different outdoor. I had photos,* *so one can't really compare. But because I had photos, they were the landmarks for me.'* The category *'Expect display'* encodes whether users already expect the display before they see it. In the interview, one user stated: *'The display was shown on the map, therefore I tried to find the next [display][...] In the first floor they did not show me how the floor after the stairs looks like. So I was just confused. So, there I couldn't say, there is the next screen'.* The category *'Display confusing'* includes situations with displays showing multiple paths and some only showing one path. While displaying multiple paths is a way to preserve privacy of individual users, not a single user pointed this out as a benefit. Instead, every user who noticed the difference complained about displays showing multiple lines being very confusing. One user stated: *'This one here, it had multiple lines. I found that confusing. It annoyed me'.* The category *'Display density'* describes whether displays are perceived as close to each other or further apart. When displays are spaced out further apart, users rely more on the phones. However, some users also perceived displays i4 and i5 as being too close to each other. The category *'Display size'* refers to the size of the display. Interestingly, while many users mentioned the (obvious) construct of display size, no one elaborated that it was particularly important to determine whether the user would look at the display. Additionally, when users were asked to rate the displays for the 'Display size' construct, they often misjudged the relative sizes of the displays. The category *'Route complexity'* is linked to the general complexity of the route. The category *'Delay'* describes whether the map is shown immediately when the user looks at the display or whether there is a delay.

6. DISCUSSION

Many of the constructs that arose in the repertory interviews support findings in the literature. The similarity scores are an indication of the relative importance of various categories and help to give a framework of what factors might be how important. In this part we discuss the most interesting categories which contain the, from our point of view, most surprising aspects. Then, we show how they are supported by the literature.

Social Context and Privacy.

Privacy is a factor that is mentioned often in the literature. It was thus somewhat unexpected that it was only mentioned by a single user in the study, and did not correlate strongly with display usage. Furthermore, the difference between the goal being the toilet and a café/coffee room was not mentioned by a single user. This may indicate that participants did not mind their navigation goal being shown on the display simply because the destination did not give away a lot of information about themselves. If this was indeed the case, it is not surprising that displaying multiple route simultaneously was not seen as beneficial and only described as being confusing. It is possible that the weak importance of privacy was partially influenced by the setup of the study, where users may have had a weaker identification with the display content. Still this effect appeared very consistently, and even when asked users stated that privacy was less important. Thus we gained the impression that although privacy does play a role regarding display usage, the importance of this factor may be lower than generally assumed. Whereas privacy did not play a prominent role, the social context of a public display was referred to as relevant by several participants. In a pretest one user was in the situation where one display in front of the train station was used by two people making a phone call, and stated to have been happy that he could choose another display next to it. Another user from the pretest declared that she would be unwilling to use the system at the train station at night due to security concerns, i. e. other people might be able to see where she was going. Users in general were more hesitant to use public displays with many bystanders around, but the primary reason seems to be not wanting to disturb them. Many users stated it was irritating if they have to stand in the way of other people. In addition, users seem to be very sensitive when they get the impression that they interrupt other people when they want to use the display. This is consistent with the observations reported in [10], where a major factor for the disuse of a semi-public display was that it also served as a clock when idle. Because people did not know whether anyone currently needs the clock, nobody dared to use the display. **Implications:** Although privacy is a factor often mentioned in the literature, our results suggest that other factors may be more important. Rather than worrying about their navigation goal being revealed to strangers, subjects were more concerned about the wider social context. Therefore, obscuring the real goal of the user (e. g. by showing multiple routes simultaneously) may not be necessary or even confusing. In terms of display choice, it seems to be important to not only take into account where decision points are located but also to consider bystanders and the flow of people around the display. If possible, displays should be chosen that are mounted in such a way that attending to them does not interfere with other people's activities.

Orientation or Confirmation.

A second important observation relates to the actual use of the displays. Even though all displays in principle provided the same information, the first displays in certain areas were used very differently from subsequent displays. Most participants used the first display on a route to learn the whole route while previewing upcoming landmarks or maps on the mobile phone. For display i1, the route shown on the display was quite short, so this process took less time. Most of the users who spotted display i3 at all repeated this process for the fifth floor of the building. Subjects relied on the subsequent screens along the route only for confirmation, i. e. to assure that they are still on the right way. While most participants stopped when looking at displays o1, o3, i1, i2, i3 and i4, participants did usually not stop or slow down when looking at displays o2 or i5 which were installed 180° to walking direction. The latter behavior has been also observed with public non-navigation displays by [9]. Only when users lost their way, they would sometimes use the screens along the route to get an overview of the route again. **Implications:** Evenly distributing display along a route may not be the best possible solution. Instead, it may be useful to identify distinct route sections and to just choose screens that are installed at the start of these sections. The first screens in a section should be optimized for a viewing time of about 30s., display the whole route and enable users to learn it. Subsequent displays merely need to confirm users that they are still on the right way, which can be achieved with a much simpler design. These displays should be designed so the user does not have to stop to see the confirmation, and be optimized for a viewing time of one to five seconds. The displays along the route would also not need to interrupt their normal programming to show the confirmation; for example showing a small arrow in one corner of the screen pointing in the right direction might be sufficient. Nevertheless, these 'intermediate' displays should still provide a means to display a full route map that users can access in case they loose their way.

Visibility.

In the experiment, most users did not actively search for displays, but only looked at them when they virtually stumbled across them, or – less frequently – when they lost their way. Many displays were not spotted at all, and those that were were only glanced at very briefly. Display i3 which was above eye height, for example, was completely overlooked by four participants. These observations are consistent with [9], where Huang et al. observed that many (non-navigation) public displays attract only few and very brief glances (one or two seconds), and are often ignored if above eye height. In addition, our results indicate that the angle of approach may impact whether a display is seen or not. Displays that were located straight ahead in the walking direction of users were looked at much more than those where users had to turn their head to see the display (e. g. display o3, i2 and i4). Users stated that they would mostly use displays that would 'naturally appear in the field of vision'. This is consistent with [22], who researched paper signs in stores and suggests to first think about where people would look anyway without a sign and then place the sign right there. In addition, displays were very likely to be overlooked or ignored in case users could already see the next landmark or another display. There seems to be a dilemma for display choice regarding social context and visibility: In order to make displays seen in the first place displays should be chosen where users walk directly towards them. In order to make users use the displays for longer, however, the users should not have to stand in the way of others. This could partially be solved by choosing high traffic locations for displays that serve mainly for confirmation, and more quiet locations for displays that serve mainly for overview. **Implications:** Clearly, an unobstructed line of sight between a person and a public display only partially determines whether that person will actually consciously perceive it. Our results indicate that in order to register with people, a display should be chosen that is placed at eye hight and within users 'natural field of vision'. In particular, choosing a display that is mounted in such a way that people will walk straight towards it while following a route will significantly increase its chances to be seen.

Focus on mobile phone or public display.

In both studies, we frequently observed users being very focussed on their phone so that they simply did not see the public displays. Subjects mentioned that they do not have to stop to use the phone and that the phone is always available as opposed to the displays, and that therefore, they rely on it more. As for displays i2 and i4, users were much more likely to look at less obvious displays if there was a reference from the phone to the display (the displays were annotated on the map). **Implications:** In order to build a system providing effective navigation support through both mobile devices and public displays, it seems advisable to explicitly account for where user focus their attention. One possible option is to directly refer from the mobile phone to the public display when the joint use might provide a benefit to the user (e. g at the beginning of a new 'route section'). Another option is to simplify the mapping task, i. e. to make it easy to match information on the phone to information on the public display (e. g. by using consistent labels, designs or symbols).

Further aspects.

There is an interesting relationship between displays and landmarks. Public screens can display landmarks, as they did in the experiment via the overview maps. At the same time, displays can serve as landmarks themselves. In this case, users do not need to look at the display content at all. A further option would be to use public displays as personalized landmarks. For example, some users in our study only had briefly glimpsed at the displays to determine whether the dot, which marked their current location on the map, was where they expected it to be. This may constitute a first step towards a personalized landmark when a public screen displays something that serves as a landmark for a particular user. During the interviews, users mentioned being confused by having multiple routes shown on the same display. This may pose a problem in terms of the scalability of the system, when multiple users simultaneously use the same public display for navigation. Personalized landmarks may be one possible solution to this problem provided that they are only meaningful to particular individuals. Another option would be to use different displays for different users in case enough displays are available.

7. CONCLUSION

Falling display costs have led to public screens rapidly proliferating in public spaces, and thus created an opportunity to (temporarily) use these displays as an extension for mobile devices. Our results suggest that although users may experience these screens as beneficial, many factors need to be considered in order to entice people to actually use public displays, including task-specific factors.

When using our guidance application overall navigation behaviour and information needs were in line with previous reports from systems relying on mobile devices. For example landmarks were still very important for the navigation task [15], and if landmarks were visible, displays were often ignored. Complex decision points require more attention from the user [19], and it is therefore not surprising that displays at such locations are used more often. Similarly, when users are very familiar with the environment, they do not need to rely on technological support, be it mobile phones or displays.

An interesting observation from our studies relates to the fact that public displays and mobile devices seem to nicely complement each other during different phases of the navigation. At the beginning of the route, displays are of more value to users, because the additional screen real estate provides a better overview of the route. Our results indicate that users often switch focus between mobile device and public display in order to prepare for the route. While they are following the route, users tend to rely more on the mobile device, possibly because it is always available and there is no need to stop (i.e. to interact with a display). During this phase, public displays are predominantly used for confirmation but mainly if users virtually stumble upon them.

However, if users loose their way and need an overview map, they are more willing to actively search for a public display, either by scanning the environment or by following a reference on the mobile device. While following the route, users generally tend to focus on the mobile device (unless they lost their way). Depending on task progression, it might therefore be necessary for the system to actively steer the attention of the users to a public display. A further noteworthy result is the role of privacy concerns. In our study, we found that privacy in public display use may play a lesser role than generally assumed. Participants attributed more importance to the general social context of using a public display than to privacy concerns. In particular, users were keen not to stand in the way of others or to disturb them. Our findings open up several opportunities for future research. Firstly, it seems worthwhile to further explore the role of displays as landmarks, i.e. their specific role in situations when pushing information to users passing by seems to be appropriate in contrast to situations where users are more willing to actively pull information from the displays. In this context it would be also very interesting to investigate how users split their attention between mobile devices and public displays in general. Finally the role of privacy and the social context needs further research to verify the findings of this paper. Overall we believe that human rather than technological factors will determine the success of pedestrian navigation systems integrating public displays and mobile devices. The results reported in this paper provide a significant first step towards a better understanding of these factors, and thus towards more successful designs and increased user acceptance.

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