

Insights into user experiences and acceptance of mobile indoor navigation devices

Katrin Arning and Martina Ziefle
Human-Computer Interaction Centre
Theaterstr. 14
52062 Aachen, Germany
+49 241 8025501
arning@comm.rwth-aachen.de

Ming Li and Leif Kobbelt
Computer Graphics & Multimedia Group
Ahornstr. 55
52074 Aachen, Germany
+49 241 8021812
mingli@cs.rwth-aachen.de

ABSTRACT

Location-based services, which can be applied in navigation systems, are a key application in mobile and ubiquitous computing. Combined with indoor localization techniques, pico projectors can be used for navigation purposes to augment the environment with navigation information. In the present empirical study ($n = 24$) we explore users' perceptions, workload and navigation performance when navigating with a mobile projector in comparison to a mobile screen as indoor navigation interface. To capture user perceptions and to predict acceptance by applying structural equation modeling, we assessed perceived disorientation, privacy concerns, trust, ease of use, usefulness and sources of visibility problems. Moreover, the impact of user factors (spatial abilities, technical self-efficacy, familiarity) on acceptance was analyzed. The structural models exhibited adequate predictive and psychometric properties. Based on real user experience, they clearly pointed out a) similarities and device-specific differences in navigation device acceptance, b) the role of specific user experiences (visibility, trust, and disorientation) during navigation device usage and c) illuminated the underlying relationships between determinants of user acceptance. Practical implications of the results and future research questions are provided.

Categories and Subject Descriptors

H.5.2 User Interfaces: Evaluation, User-centered design.

General Terms

Human Factors, Experimentation, Measurement

Keywords

Indoor Navigation, Mobile Projector, Mobile Screen, Acceptance, Disorientation, Trust, Visibility, User Study,

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Augmented Reality

1. INTRODUCTION

Location-based services, which can be applied for navigation purposes, are a key application in mobile and ubiquitous computing. Based on rapid technical developments in areas of localization technologies, mobile devices, display technologies, and data transfer rates, research activities concerning indoor navigation aids have considerably increased [22]. The majority of indoor navigation aid solutions use mobile screens of smartphones or PDAs for displaying navigation information, e.g. [24,31]. However, miniaturization brought compact sized mobile projectors (pico projectors) to the markets, which might also be used for navigation purposes. Projectors are a flexible medium for large displays that are suitable for public viewing purposes. Besides being used for display purposes, the projection can also augment real world objects with visual overlay. Due to physical size constraints, traditional applications of projectors were restricted by a fixed installation with very limited mobility. Pico projectors, in contrast, can be used as a mobile personal device in pervasive computing [27] either as an add-on to standard handheld devices or integrated into smart devices. Combined with indoor localization techniques [24, 21], projector-based navigators can augment the environment with route information, turn-by-turn instructions, points of interest, etc. Compared to a mobile screen based navigation interface (e.g. a 2D map), the projector based navigation interface directly projects the information in the environment, so that there is no need to switch between the screen and the real world. On the other side, the visibility of the projected content might be limited due to the illumination or the material of the projection surface.

A key prerequisite in designing successful navigation systems is - apart from technical reliability and quality of navigation information - end-users' acceptance. The risk of market failure is high, as long as user demands are not adequately considered in system design and users do not perceive the usefulness or benefits of a system [20]. Technology acceptance research seeks to explain and predict the perception and adoption of technologies by end-users. Technology acceptance theories such as the Technology Acceptance Model (TAM) [8,9] primarily

focus on job-related usage of information and communication technologies (ICT). Since technology acceptance is highly context-specific [3], existing knowledge from ICT-related technology acceptance research or the well-studied car navigation context cannot be easily transferred to the indoor or pedestrian navigation context. An extensive literature analysis revealed that end-user acceptance and experiences of indoor navigation systems have not been systematically and empirically evaluated so far. Moreover, user experiences regarding the usage of different navigation devices, such as a mobile projector in comparison to a conventional screen-based navigation device (e.g. in smartphones), have also not been systematically investigated. Therefore the following research questions were addressed:

1. What are the major influential factors and antecedents of mobile indoor navigation device acceptance?
2. How do user experiences and acceptance differ with regard to different navigation devices (mobile projector vs. mobile screen)?
3. How do user factors such as spatial abilities, self-efficacy or familiarity influence navigation device acceptance?
4. As the visibility of the projected content might be a limiting factor in projector usage: What are the major sources of visibility problems in the usage of a mobile projector as a navigation device?

1.1 RELATED WORK

In recent years many companies and organizations have been collecting and providing indoor map and route information, e.g. Google indoor navigation and OpenStreetMap indoor mapping. The indoor localization service can be provided by various techniques, e.g. [24, 21]. Combining existing digital maps and indoor positioning techniques, a mobile projector based navigation device can provide users a novel navigation interface.

Previous research of indoor navigation was mainly focused on the use of the small sized mobile displays as visual output. Exceptions are the work of Krüger [19], where participants navigated through a zoo using either a PDA or a head mounted clip-on, and the study of Münzer [23], where - in the same zoo setting - participants navigated either using a PDA or printed maps. A systematical experimental comparison of navigation display types such as mobile displays in comparison to projectors was not found.

Since pico projectors are capable of augmenting real world objects with visual overlay, they provide more choices when designing graphical navigation interfaces. Rukzio et al. give an overview of personal projector applications for pervasive computing [28], where projector-based navigation belongs to the category "Augmented Reality". Winkler et al. proposed the concept of indoor navigation for shopping malls through a mobile projector [35]. Wecker et al. introduced Pathlight [34] for in-museum navigation

using a handheld projector. The turn-by-turn instructions were given by projection of landmark photos augmented with directional arrows. Several research challenges were listed to be answered, e.g. user acceptance, preferred projection surface, visibility, etc. Rukzio et al. [28] presented a public projection based mobile navigation approach. A public projector displayed a rotating arrow on the floor at a junction. When the direction of the projected route changed the passengers' mobile device would indicate this information through vibration. When the mobile projector is used for Augmented Reality purposes, it requires adaptation to the presentation surface, i.e. pre-warping the image for distortion-free projection. Tajimi et al. [32] applied a stabilization approach for floor projection with a hip-mounted projector. To improve the visibility of the projected content while the user is walking, a tilting sensor was used to detect and compensate the motion of the projector.

Although pedestrian navigation systems in general and, more specifically, the use of projectors for a public display of navigation information have been discussed and researched in recent years [27,13,38], end-users' perception of these systems and the acceptance of indoor navigation systems was not systematically included and evaluated. Studies which considered acceptance focused on general satisfaction levels, ease of use and the perceived usefulness of a technology. Heinroth and Bühler, for example, assessed the usefulness, ease of use, convenience, and willingness to utilize a speech-based pedestrian navigation system [17]. Rukzio assessed disorientation events, usability, satisfaction and workload in the evaluation of a "rotating compass", a public display technique [29]. However, no comprehensive assessment of navigation system acceptance and projectors as display medium was carried out, including further navigation-relevant aspects such as privacy, trust into navigation information given, and perceived disorientation during wayfinding. Since the projection is not only visible to the user but also other people at the same location, privacy concerns are a serious issue that should be adequately addressed. Greaves et al. [15] reported a study about the social impact and privacy concerns regarding the usage of mobile projectors in public spaces. In the NAVITIME study, where mobile-phone-based navigation and other location-based services were evaluated, users perceived disorientation when using the device, but the sample size ($n = 2$) was too small to interpret and generalize this finding [2]. The assessment of a broader range of user experiences in the present study will allow for determining the most relevant user experience factors and their causal relationships contributing to navigation device acceptance. These factors should be addressed as a starting point in further design activities of indoor navigation systems, because they are the essential influential factors of end-users' acceptance.

A further "blind spot" of user-centered research in the field of indoor navigation is the systematic inclusion of user

factors. Although indoor and pedestrian navigation aid solutions exist for specific user groups with special needs, e.g. visually impaired people [7] or senior users [13], a systematic inclusion of user factors such as cognitive abilities or attitudinal traits is missing. In the present study we therefore connect relevant user factors for mobile device interaction such as spatial visualization abilities and technical self-efficacy [4, 5] with user experiences, workload, performance parameters, and acceptance. This approach allows the identification of user groups that might need special design considerations.

2. METHODOLOGY

In the present study we investigated end-users experiences and acceptance of two different indoor navigation devices (screen vs. projector) with the aim of modeling navigation device acceptance by applying structural equation methods.

2.1 Statistical approach

Since device acceptance and its antecedent user experiences are not directly observable, they are conceptualized as *latent variables or constructs* and measured through item indicators, which represent the respective latent variable. In order to determine causal relationships among user experiences and to predict user acceptance, Partial least squares (PLS), a component-based structural equation modeling (SEM) technique, was employed. In contrast to covariance-based SEM, PLS is not limited to reflective definition of constructs, but also allows for formative constructs, whose item indicators can be interpreted as cause measures. PLS has softer distributional assumptions, smaller sample size requirements, and is especially suited for exploratory model development, which is well suited for the rather unexplored issue of indoor navigation system acceptance. As modeling software, Smart PLS was used [26]. For the comparison of latent variable scores for projector and screen usage ANOVAs with repeated measurement were applied.

2.2 Research hypotheses

Based on the assumptions of the technology acceptance model [8] as well as on relevant user experience research in mobile and ubiquitous computing [4,5,12,15,28], we investigated the following research hypotheses:

User factor hypotheses

H1a: Spatial ability is negatively associated with disorientation and workload, and positively associated with performance.

H1b: Technical self-efficacy (TSE) is positively associated with trust and negatively related to privacy concerns.

H1c: Familiarity acts as control variable and is negatively related to disorientation and positively related to performance.

User perception hypotheses

H2: Visibility problems are negatively related to ease of use and performance.

H3: Trust is positively related to usefulness.

H4: Disorientation is negatively related to ease of use and

performance.

H5: Privacy concerns are negatively related to usefulness.

H6: Workload is negatively related to performance.

H7: Performance is positively related to ease of use.

H8: Ease of use is positively related to usefulness.

Acceptance hypotheses

H9: Usefulness is positively related to acceptance.

Device hypotheses

H10: Privacy concerns are higher for projector usage.

H11: Visibility problems are higher for projector usage.

H12: Changing light conditions are the main sources of visibility problems during projector usage.

2.3 Navigation devices

User experiences and acceptance of two different navigation display devices, a mobile screen (of a smartphone) and a mobile projector, were evaluated.

Mobile screens are widely used for navigation purposes to display digital maps, virtual guides (Google Street View) and augmented reality (AR) navigation interfaces [24,25]. Visibility is less affected by the light condition for indoor scenarios. Moreover, as a personal display the screen content is only viewable to the user, so privacy concerns considering the displayed content might be less pronounced than using a projector. Compared with a *mobile projector*, the screen's output space is limited by its size. In non-AR navigation solutions users have to frequently switch visual attention between the display and the real world. In AR solutions although the video-see-through enables environment awareness, it is still restricted by the camera's field of view. Since the pico projector is held in the users' hand while walking, the projected navigation interface is distorted due to the change of the angle between the projection axis and the projection surface. To avoid distortion effects, we pre-warped the map navigation interface by referring to the device pose provided by accelerometer and gyroscope (Figure 1).

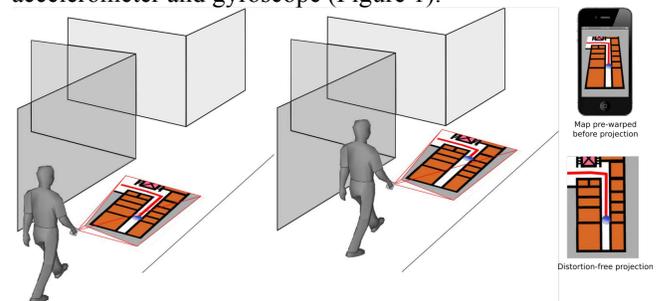


Figure 1: Distortion-free projection.

We implemented the navigation prototype application on an iPhone4. A SAMSUNG SP-H03 Pico Projector (30 ANSI Lumens) was used and connected to an iPhone4 via VGA cable (Figure 2). The heading direction and the device motion were taken from the integrated sensors of the iPhone4. When using the mobile screen as navigation aid, the participant held the iPhone4 as navigator and the navigation information was displayed on the screen. Using the projector, the participant held the hardware as pictured

in Figure 2 and the information was projected to the floor or other surfaces he/she prefers.

As *navigation information* a map of the environment was projected or displayed, which provided survey knowledge to the participants. According to spatial cognition theories, survey knowledge is the most elaborated type of spatial knowledge [33]. It supports the construction of an adequate mental representation of an environment, which can be used for route planning, wayfinding and the development of alternative routes in case of getting lost [18]. In the map, a blue dot indicated the user's current position and the red line represented the route to the destination (Figure 3).



Figure 2: The projector based navigator prototype (Dimension: 32x11.5x7 (cm) Weight: about 1kg)

When the position was updated, the dot and line were refreshed as well. We utilized the integrated magnetometer to detect the heading direction and align the image to the current orientation. Device motion was used to correct projection distortion. In our prototype setup, the indoor position was given by a manual localization method in which the experimenter followed the participant and sent location updates from a host device to the participant's navigation aid via a portable wireless network.



Figure 3: Navigation information projected on the floor and displayed on the mobile screen.

The *navigation or testing area* for indoor navigation was within the university campus. Based on the floor plans of selected buildings, the map was created as an overlay to a standard google map view. Every participant had to use

both, the mobile screen and the projector (balanced within-design to avoid sequence effects). The complexity of all routes (route length, number of junctions and branches) was equalized. The ambient illumination on the routes was comparably good (mainly daylight lamps).

2.4 Latent variables measures

We assessed three categories of variables for our reflective acceptance model constructs: end-user experiences, navigation performance, and individual user factors.

End-user experiences (described below in alphabetical order) were collected via subjective ratings. Participants had to indicate their answers on a 6-point Likert Scale (1 = strongly disagree, 6 = strongly agree). Item examples are given in brackets.

Acceptance: Users' acceptance of the navigation devices was immediately assessed after route completion ("How did you like the navigation during the last navigation task?").

Disorientation. We assumed using a navigation device supports building up a mental representation of the environment") [13], e.g. knowing where to be. Therefore participants had to rate their perceived disorientation ("I had difficulties to orientate in the building.").

Ease of Use and Usefulness. For the assessment of perceived ease of use ("The navigation system was easy to use") and perceived usefulness ("With the navigation system I reached my destination faster"), a shortened version of the original items of the Technology Acceptance Model [8] was used.

Privacy. We assumed that the "public" projection of navigation information would affect users satisfaction when using the navigation device ("I felt uncomfortable when other people saw me using a navigation system") [15].

Trust. Relying on the given navigation information is of great importance for users' acceptance [12], therefore we assessed trust during navigation ("I could trust the information of the navigation system on my way".).

Visibility. As lighting conditions were assumed to influence the visibility of navigation information, we assessed the visibility of the projected or displayed navigation information ("The map was always visible on the display."). In the projector condition we additionally assessed potential sources of visibility problems (additional formative construct "disturbing factors").

We assessed perceived *workload* of each condition by using the standard NASA-TLX questionnaire [16]. Using a scale from 0 to 100 participants rated the six subscales (e.g. "How much mental and perceptual activity was required?") after each condition. Finally participants had to weigh, which of the dimensions contributed most (and least) to the workload they experienced during navigation. The weighted average of the six subscales reflected the overall workload of each navigation device condition as an integrated measure.

Performance. In order to evaluate participants' wayfinding performance, percentage preferred walking speed (PPWS) was calculated. PPWS reflects the extent to which the use of the navigation aid disrupts normal walking [14]. Before the test, participants were asked to walk a fixed distance in their normal indoor walking speed (baseline). The preferred walking speed (PWS) of each participant was calculated by the distance and completion time. To calculate PPWS, participants' average walking speed (AWS) was compared to PWS ($PPWS = (AWS / PWS) \times 100\%$). Any negative disrupt of the navigation aid will result in a decreased percentage of PWS. Higher values indicate better wayfinding performance.

Individual user factors. Psychometric tests were applied to assess user factors:

Spatial visualization ability. Participants completed a spatial visualization test taken from the Kit of Factor-Referenced Cognitive Tests (Paperfolding test [10]). In this two-dimensional spatial task, 20 items are presented, which show the illustration of a sheet of paper, which is folded several times and finally punched. Participants have to select one of five drawings to show how the punched sheet would appear when paper is fully opened. The maximum score to be reached was 20.

Technical self-efficacy (TSE). Technical self-efficacy, i.e. the confidence in one's own ability to solve technical problems, was measured by the TSE-Questionnaire [6]. Participants were given the short version of the test, containing eight items. The items had to be confirmed or denied on a five-point-scale from 1 (totally disagree) to 5 (totally agree). The maximum TSE-score was 40. Several studies, which assessed the reliability and validity of the TSE [4, 5, 6] showed satisfactory results and proved the construct of subjective technical confidence as a technology-related personality trait.

Familiarity. Familiarity with the navigation was assessed as a control variable on a six-point Likert-scale.

2.4 Data collection procedure

In the beginning of the study, we measured participants' preferred walking speed (PWS). Psychometric testing procedures were applied in order to assess spatial visualization ability and technical self-efficacy. A short tutorial was given to teach the participant to use the navigation devices. Participants were told to freely explore suitable projection surfaces. Then the experimenter guided participants to the starting point of the testing route. He/she had to walk to the destination following the navigation instructions given on the navigation device. The completion time of every route was recorded on the navigator device to compute actual walking speed (AWS). After reaching the destination of each route, workload measures, end-user perceptions, and acceptance of the specific navigation device were assessed. The overall duration of the experiment was about one hour and 15 min.

2.5 Sample

A total of 24 participants, 19 women and 5 men, in an age range between 21 and 28 ($M=23.5$; $SD=2.3$) took part in the study. Participants were mostly university students (social sciences) and fulfilled a course requirement. 79% of the participants were unfamiliar with the testing location. While participants reported solid experience of using smart phones, they were novices regarding the using of mobile projectors. All participants had at least limited experience using the broad range of navigation technologies (e.g. sat navs or geo-caching).

3. RESULTS

First, we report on the measurement quality results of our acceptance models, followed by a contrast of latent variable scores for the two navigation devices under study. Finally, the structural models of projector and screen acceptance and the results of hypotheses testing are presented. The explained variance (R^2) of the acceptance-variable indicates the overall predictive power of our models.

3.1 Measurement model results

The analysis of the measurement model showed that the reliability and validity of the items used to represent each latent variable were acceptable in both acceptance models (see Table 1 and Table 2; quality criteria were calculated for multi-item constructs).

Table 1: Descriptive statistics for projector model scales.

Item	M	SD	Item total corr.	AVE	Comp. reliab.	R ²	Cronb. alpha
Dis1	2.13	0.90	0.78	0.62	0.87	0.65	0.80
Dis2	1.71	0.81	0.76				
Dis3	1.75	0.94	0.82				
Dis4	2.17	0.96	0.79				
Fam1	4.46	1.35	0.92	0.84	0.91		0.80
Fam2	4.42	1.32	0.91				
TSE1	4.13	1.08	0.86	0.70	0.93		0.93
TSE2	2.75	1.19	0.89				
TSE3	3.79	1.35	0.81				
Trust1	5.08	0.78	0.86	0.80	0.89	0.62	0.76
Trust2	4.42	1.21	0.93				
Trust3	4.46	1.25	0.91				
Ease1	4.96	0.91	0.84	0.77	0.87	0.71	0.71
Ease2	4.54	1.18	0.89				
Ease3	5.00	0.78	0.92				
Usef1	4.74	0.92	0.92	0.74	0.89	0.77	0.82
Usef2	4.78	0.74	0.85				
Usef3	5.04	0.86	0.81				
Priv1	2.67	1.40	0.90	0.90	0.95	0.89	0.89
Priv2	2.46	1.35	0.94				
Vis1	5.00	0.88	0.80	0.64	0.90	0.58	0.86
Vis2	4.88	1.08	0.78				
Vis3	4.04	1.04	0.84				
WL	13.1	9.45					
Perf	0.85	0.10				0.34	
Acc	5.25	0.71				0.61	

User factors and latent variable items, which had no significant effect (t -values < 0.7), were removed from the model, which only had minor effects on the explained variance (R^2) in the outcome variables. All latent variables had good psychometric properties. All factor loadings (item-total correlations) exceeded the threshold value of 0.7, i.e. variation in the items was mostly explained by the underlying latent variables. Construct reliability measured by Cronbach's alpha was above 0.7 for all constructs. The measure of internal consistency (composite reliability > 0.7) and convergent validity ($AVE > 0.5$) were above their respective thresholds. All in all, we concluded that the measures were valid.

Table 2: Descriptive statistics for screen model scales.

Item	M	SD	Item total corr.	AVE	Comp. reliab.	R ²	Cronb. alpha
Dis1	1.79	0.88	0.71	0.66	0.89	0.47	0.83
Dis2	1.63	0.92	0.84				
Dis3	5.42	0.83	0.90				
Dis4	5.29	0.69	0.79				
Trust1	1.50	0.59	0.87	0.75	0.90	0.21	0.85
Trust2	4.88	0.99	0.89				
Trust 3	5.13	0.80	0.84				
Ease1	1.38	0.58	0.95	0.85	0.95	0.62	0.91
Ease2	5.17	0.82	0.85				
Ease3	1.43	0.59	0.96				
Usef1	1.83	0.78	0.82	0.74	0.90	0.52	0.83
Usef2	1.83	0.78	0.87				
Usef3	1.58	0.58	0.88				
Priv1	5.04	0.86	0.95	0.90	0.95	0.89	0.89
Priv2	4.79	1.02	0.95				
Vis1	1.33	0.48	0.85	0.83	0.94	0.90	0.90
Vis2	1.38	0.49	0.97				
Vis3	1.42	0.58	0.91				
WL	10.0	9.81					
Perf	0.88	0.08				0.51	
Acc	5.39	0.54				0.50	

3.1.1 Device-specific contrast of user experiences and acceptance

ANOVAs with repeated measurement were calculated in order to assess differences in latent variable scores of screen and projector user experiences and acceptance (see Figure 4). In order to ensure comparability of the different latent variable scores, the single construct indicators (Min = 1, Max = 6) were aggregated to a total scale index and transformed to Max = 100.

Users' *acceptance*, which was generally high ($M_{total} = 90.1$, $SD = 8.8$), was significantly higher after navigating with the screen than with the projector ($M_{screen} = 92.7$, $SD = 9.0$, $M_{projector} = 87.5$, $SD = 11.8$; $F(1,23) = 4.9$, $p < 0.05$).

Perceived *disorientation* was comparably low and did not differ for both navigation devices ($M = 30.6$, $SD = 9.7$, $M_{screen} = 28.6$, $SD = 11.07$, $M_{projector} = 32.5$, $SD = 11.6$, n.s.).

The *ease of use* for both navigation devices was rather high ($M_{total} = 85.5$, $SD = 9.5$), but using the screen was perceived as easier than using the projector ($M_{screen} = 90.8$, $SD = 10.3$, $M_{projector} = 80.2$, $SD = 13.1$; $F(1,22) = 13.4$, $p < 0.01$).

Navigation *performance* was significantly reduced when navigating with the projector in comparison to the screen ($M_{projector} = 0.85$, $SD = 0.1$, $M_{screen} = 0.91$, $SD = 0.09$; $F(1,23) = 12.5$, $p < 0.01$).

Participants reported low *privacy* concerns ($M_{total} = 38.7$, $SD = 17.1$), which were significantly higher when using the projector compared to the screen ($M_{screen} = 34.7$, $SD = 14.9$, $M_{projector} = 42.7$, $SD = 21.2$; $F(1,23) = 8.6$, $p < 0.01$; H11 confirmed).

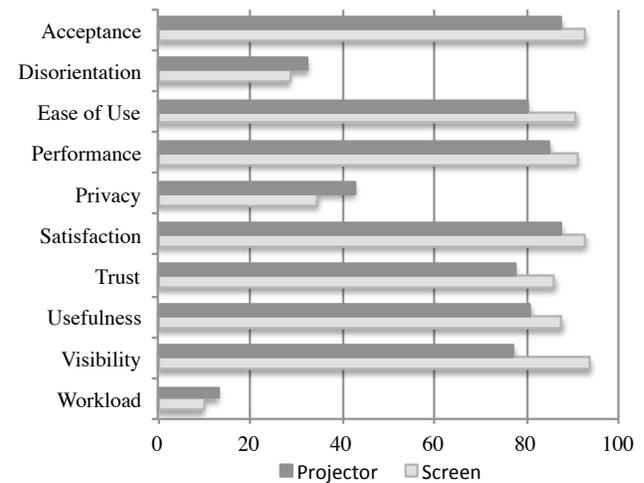


Figure 4: Mean values of end user perceptions, performance, and acceptance for both navigation devices.

Although *trust* in both navigation devices was comparably high ($M_{total} = 81.8$, $SD = 11.1$), it was significantly higher when using the screen than when using the projector ($M_{screen} = 86.1$, $SD = 11.7$, $M_{projector} = 77.5$, $SD = 14.3$; $F(1,23) = 9.1$, $p < 0.05$).

Perceived *usefulness* of the navigation devices was rather high ($M_{total} = 84.3$, $SD = 9.7$). The usefulness of the screen was rated significantly higher than the usefulness of the projector ($M_{screen} = 87.7$, $SD = 10.3$, $M_{projector} = 80.9$, $SD = 12.1$; $F(1,20) = 8.2$, $p < 0.01$).

The *visibility* of navigation information was perceived as generally high ($M_{total} = 85.5$, $SD = 8.0$). Though, visibility was better using the screen than when using the projector ($M_{screen} = 93.8$, $SD = 7.9$, $M_{projector} = 77.3$, $SD = 14.4$; $F(1,23) = 22.9$, $p < 0.001$; H10 confirmed).

Overall *workload* was rather low ($M_{total} = 11.6$, $SD = 8.4$) and it did not differ using the screen or the projector ($M_{screen} = 10.0$, $SD = 9.8$, $M_{projector} = 13.1$, $SD = 9.4$, n.s.).

3.3 Structural model results

The PLS analysis yielded path coefficients for the structural model. Levels of significance were estimated using t-statistics derived from a bootstrapping procedure with 200 re-samples. Overall, the model explained major portions in the variation of navigation device acceptance: about 50% of screen acceptance (Figure 5) and even 61% of projector acceptance (Figure 6).

User factors: *Spatial abilities* neither affected disorientation, workload, nor performance in both navigation aid models (H1a rejected). TSE and familiarity were not related to trust or privacy concerns in both models (H1b and H1c rejected). Instead, in the projector model, higher levels of TSE were associated with a higher ease of using the projector and higher levels of familiarity led to higher trust in navigation information. Interestingly, familiarity was not directly related to disorientation or performance.

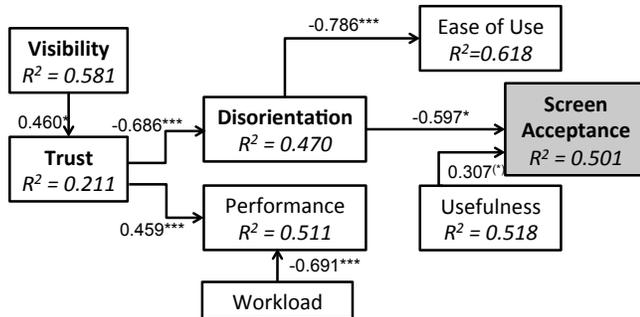


Figure 5: Screen acceptance model.

(*** = $p < 0.001$, ** = $p < 0.01$, * = $p < 0.05$, (°) = $p < 0.1$).

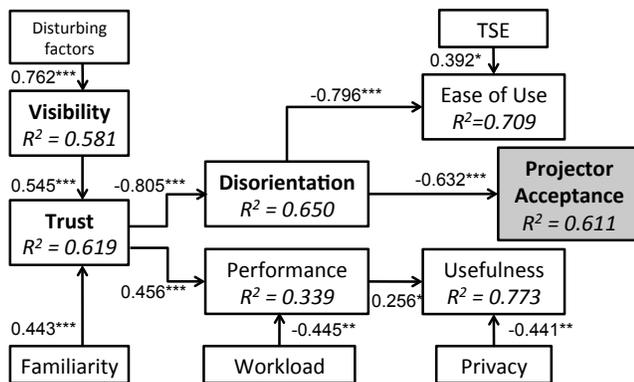


Figure 6: Projector acceptance model.

(*** = $p < 0.001$, ** = $p < 0.01$, * = $p < 0.05$).

User experiences: The formative definition of the construct “*disturbance factors of visibility*” in the projector model yielded changing light conditions as significant main source of visibility problems (H12 confirmed). The other factors such as patterned floor characteristics, reduced contrast of the projection, dark floors and the change between different projection surfaces did not significantly affect the visibility of the projection. Contrary to expectations, *visibility* did not directly influence ease of use and performance in both navigation device models (H2b rejected), but strongly affected trust in navigation information of both devices.

Interestingly, visibility directly influenced disorientation, but exerted an indirect effect via trust. *Trust* neither affected usefulness of the screen nor of the projector (H3 rejected), but strongly affected navigation performance in both models. Most importantly, trust was found to be the strongest predictor of disorientation in both models: the lower the trust in navigation information, the higher was the level of disorientation. Regarding *disorientation*, no direct effect on performance but a strong impact on ease of use was found for screen and projector usage: low levels of disorientation led to high ease of use (H4 partly confirmed). Low *privacy* concerns were related to high levels of usefulness only in the projector model (H5 partly confirmed). Low *workload* levels were related to high navigation performance, but had no effect on ease of use (H6 partly confirmed) in both models. Navigation *performance* was not related to ease of use in both models (H7 rejected), but in projector usage, high performance levels led to high levels of usefulness. *Ease of use*, which was mostly predicted by disorientation in both models, was positively related to usefulness only in the projector model (H8 partly confirmed). *Usefulness* was not related to acceptance in the projector model, but screen usefulness was related to acceptance (H9 partly rejected).

Acceptance: *Acceptance* of both navigation devices was mainly determined by disorientation during navigation. For screen usage, perceived usefulness additionally influenced acceptance.

To sum up, user factors only had minor affects on navigation device acceptance and its antecedent user experiences. Among user experiences, visibility, trust and disorientation were the most powerful predictors of acceptance: visibility affected trust, which strongly influenced perceived disorientation, which strongly determined device acceptance.

4. Conclusions

We will now discuss the findings regarding the determinants of mobile navigation device acceptance, device-specific differences, and the impact of user factors on user experiences and acceptance. Also, methodological considerations and future research questions are outlined.

Determinants of navigation device acceptance

Our findings extend prior research on navigation device acceptance by including user factors, linking user experiences and performance to acceptance, and empirically validating the relationships. The presented structural models, which exhibited adequate predictive (explained variance exceeded 50% in both models) and psychometric properties, clearly pointed out a) similarities and device-specific differences in navigation device acceptance, b) the role of specific user experiences during navigation device usage and c) uncovered the underlying relationships between determinants of user acceptance.

Our acceptance models suggest a *causal sequence of user experiences* during navigation device interaction, which

underlies the formation of user acceptance: perceived *visibility* of navigation information influences *trust* in navigation information, which is decisive for perceived *disorientation*, which determines user *acceptance* of navigation devices. This causal sequence and the significant role of visibility, trust, and - most important - disorientation in the formation of acceptance were proven for both navigation devices. Accordingly, research and developmental activities will have to focus on improvements of these aspects of user experience as relevant *starting points* for indoor navigation system design. The fact that disorientation was the most powerful predictor of acceptance for both devices (screen and projector) suggests, that users' orientation during indoor navigation in general needs to be supported. Apart from improving the visibility of the navigation information content, the quality of spatial information given should be critically assessed (e.g. by enriching the map with landmark information) in order to improve trust and to reduce disorientation. Interestingly, *workload* and navigation device *performance* were neither direct nor major determinants of acceptance. This finding suggests that design activities and user studies should not only focus on workload or performance aspects of system interaction. Apparently, user experiences overlap user performance in acceptance formation. Overlooking user experiences during navigation system design could therefore lead to detrimental effects on user's acceptance of navigation devices.

Device-specific differences in user experiences and acceptance

The acceptance models also provided insights into device-specific differences of user acceptance. *Privacy* concerns did not play a role in predicting screen acceptance, but they affected usefulness perceptions after projector usage due to the "public display" of navigation information (Figure 7). The device-specific relevance of privacy additionally proves the validity of our acceptance models.

Further differences refer to *usefulness* and its relationships. First, in the projector model, performance had an impact on usefulness, which did not apply to the screen model. Second, usefulness of screen usage was a direct predictor of screen acceptance, whereas there was no direct relationship between usefulness and acceptance in the projector model. We assume both findings to be a consequence of the first exposure to the novel projector interface in comparison to the more familiar screen interface. Perceived usefulness comprises the benefits of system usage. Due to the "mandatory", experimental and novel context of projector usage, which interfered with the perception of projector benefits, participants referred to their navigation performance with the projector as indicator for usefulness. Since the screen interface was more familiar to our participants due to mobile or smartphone usage, we assume that more general benefit cognitions were activated for usefulness and acceptance ratings, which did not only refer to the actual experimental navigation system usage

experience. Users' *trust* in navigation information during screen usage was less affected by visibility issues in comparison to projector usage. Visibility ratings for the screen interface prove that the visibility of navigation information was not an issue for screen interaction.



Figure 7: Bystanders watching the "public" navigation information of the mobile projector

We assume that the quality of navigation information became more important for screen users' trust as they did not have to struggle with visibility problems of the projection. However, contrary to our expectations, *visibility* problems during projector usage were not the main "acceptance killer". Although users often mentioned visibility aspects - especially after using the projector - visibility problems were not directly related to acceptance. Nevertheless, changing light conditions were identified as major source of visibility problems in projector usage. In order to tackle visibility problems (especially in daylight conditions) a brighter projector or miniaturized laser projector should be used in future studies.

The comparison of navigation devices on their latent variable scores congruently showed that users favored the screen as indoor navigation device. After navigating with the projector, users reported higher disorientation levels, lower trust, ease of use, usefulness and acceptance as well as higher privacy concerns and visibility problems. Regarding navigation performance, the projector apparently exerted an intrusive effect, as user's normal walking speed dropped when navigating with the projector. Both navigation devices imposed a comparably low workload level on users. This is an important finding as it shows that both navigation devices are basically suitable for "real-world" navigation purposes. A serious interference (in terms of cognitive overload) of navigation device usage with normal pedestrian wayfinding activities can be ruled out. As mentioned before, we assume that the comparably

low acceptance of the projector might have been caused by the well-described reluctance towards technical innovations and technical devices users are unfamiliar with [30]. Users' often tend to react negatively to novel devices and interfaces because they do not immediately perceive their usefulness compared to conventional devices [9,1,4,5]. As the mobile projector technology was a novelty for all our participants, we assume that the interaction time with the projector (approx. 30 min) was not sufficient to overcome the initial caution and to perceive the usefulness of projected navigation information. However, many participants doubted the suitability of a projection for common indoor pedestrian navigation purposes, especially referring to privacy issues and to a visual overload of projected information in the environment when several people use a projector as navigation device. Before removing the projector of the navigation device research agenda, future studies should investigate user acceptance in different "real-life" application scenarios, e.g. projector usage for ambulance staff in indoor emergency situations, where the benefit of projected navigation information might be higher.

Impact of user factors

In contrast to other findings in the context of mobile device performance [3,10], user factors played a minor role in predicting navigation device acceptance. Especially screen acceptance was not affected at all by user factors. We assume that the variation of user factors was too low to exert a statically significant effect due to the homogenous sample of young, technology-prone users with a high level of experience in interacting with mobile screens. The homogeneity of our sample might also be the reason for the absence of spatial ability effects. However, in the projector acceptance model, *technical self-efficacy* and *familiarity* were related to user experiences. Projector users' trust in navigation information was higher when they were familiar with the navigation environment. We assume that familiarity acted as a control mechanism which proved the "trustability" of the navigation information. Regarding the role of TSE, we found that participants with high TSE also perceived a higher ease of use. In order to enhance ease of use for participants with low technical self-efficacy, not only navigation system characteristics should be improved but also adequate trainings or manuals should be provided.

Methodological considerations and future studies

In order to validate our conclusions, user acceptance of indoor navigation devices should be evaluated in "real" indoor application scenarios, e.g. a) in an emergency scenario, when ambulance staff needs to be quickly guided to a patient, or b) in supporting way-finding situations of older users, e.g. when senior users need to find their requested products in a supermarket. From a technical point of view, future technical research activities should focus on smaller projection interfaces, in order to disentangle the effects of hardware and projection characteristics, and to improve usability and convenience of mobile projectors. Since a

rather homogenous sample was under study, future studies should replicate our findings with more heterogeneous samples (e.g. older and less technology-experienced persons). Also we should be aware that the young and rather homogenous user group examined here might not be representative for the whole group of potential users (frail and older users), which could benefit from this technology. The quantitative evaluation of navigation devices should be supplemented by qualitative interviews, where user requirements in concrete application scenarios, potential acceptance barriers as well as further predictors of user acceptance can be identified.

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