Investigating the Balance between Virtuality and Reality in Mobile Mixed Reality UI Design – User Perception of an Augmented City

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ABSTRACT
Examples of mixed reality mobile applications and research combining virtual and real world data in the same view have emerged during recent years. However, currently there is little knowledge of users' perceptions comparing the role of virtual and real world representations in mobile user interfaces (UIs). In this paper, we investigate the initial user perceptions when comparing augmented reality and augmented virtuality UIs in a mobile application. To chart this, we conducted a field study with 35 participants, where they interacted with a simulated mobile mixed reality (MMR) application with two alternative UI designs, and an online survey completed by over a hundred people. Our findings reveal perceived differences e.g. in immersion, recognition, clarity and overall pleasantness, and provide insight to user interface design and methodological challenges of research in the area of mobile mixed reality.

Author Keywords
Mixed reality; augmented reality; augmented virtuality; mobile interaction; user studies.

ACM Classification Keywords
H.5.1 [Multimedia Information Systems]: Artificial, Augmented, and Virtual Reality, Hypertext Navigation and Maps, location-based services (LBS)

INTRODUCTION
The use of mobile phones has quickly evolved beyond the use cases with which they were first associated. The phones use more and more information that is derived from the environment, external databases, or content created by social networks rather than from the device itself. Mobile mixed reality (MMR) is one of the new emerging trends. It utilizes information both from the physical surroundings and digital data, and fuses them together into a combined view. In combining the real and virtual world information, mixed reality applications can be categorized based on the balance between virtual and real. Milgram & Kishino define a virtuality continuum with virtuality and reality at opposite ends, on which mixed reality applications can be placed [17]. Whereas research and industry have introduced applications and concepts for both augmented reality and virtual representations of the physical world, there has been little research comparing the HCI qualities of these approaches, especially from the user experience (UX) perspective.

We were interested in the user perceptions of the balance between virtuality and reality in mobile mixed reality applications for augmenting the urban environment. To investigate the phenomenon, we created two simulated mobile mixed reality applications, one based on an augmented camera view and the other on a virtual 3D city model, illustrated in Figure 1. In the following, we refer to the 3D model based UI view as augmented virtuality view, according to its characteristics on the virtuality continuum presented in [17].

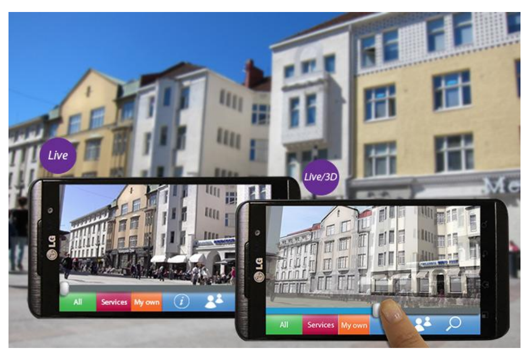

Figure 1. Concept designs of the studied MMR application prototype based on the camera view and a 3D model.

To chart the user perceptions, we conducted a two-phase user study including interviews in the field with 35

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participants, who interacted with a simulated prototype *in situ,* and an online survey with over a hundred participants. Our research aims to bridge the gap in understanding the characteristics of virtuality and reality in mixed reality UI design. The novel contribution of our paper lies in assessing comparable UI designs with augmented reality and augmented virtuality approaches, and using a study setting that has not been previously utilized in this domain. Our work provides novel information on the balance between virtual and real elements for mobile mixed reality UIs, and benefits researchers and UI designers working on mobile mixed reality, augmented reality and location-aware services.

RELATED WORK

Mobile Mixed Reality

In this paper, we consider mixed reality as *the general term for merging of real and virtual worlds*, as it is defined by Milgram & Kishino [17], where the designs and applications mixing these two qualities fall somewhere along the virtuality continuum. Whereas augmented reality (AR) builds on bringing digital information on top of a physical world view, the category of augmented virtuality (AV) is located in between AR and virtual worlds (VWs), where, according to [17], VWs display completely computer generated graphics [17]. In our case the virtual world model was originally based on a laser scanned and photographed city environment. This was then modeled to create a virtual world, including representation of colors and materials. Hence, in the following, we refer to our UI design utilizing this virtual world model as an augmented virtuality UI. However, as Milgram & Kishino point out, the gray area between predominantly real and virtual worlds is somewhat fuzzy, and as technologies progress, the borderlines between definitions become less straightforward [17].

Within the domain of mobile augmented reality (AR), the applications can roughly be divided into two main categories, AR browsers and image recognition based approaches [21]. In the early 1990s walking around with a mobile AR system required the use of a head mounted display [2]. This compares to the current situation where mobile mixed reality (MMR) applications have already emerged from research to off-the-shelf products on mobile phones, with applications such as Layar[1], Wikitude[2], and Google Goggles[3] being commonly available.

A typical UI style used with mobile augmented reality applications utilizes the camera view, which is overlaid with icons, text boxes or other UI elements, which are linked to the physical environment. Looking at the physical objects through a mobile phone screen, which augments them with digital information, is also called a 'magic lens' approach (see e.g. [24]). In addition to these augmented reality browsers, mobile mixed reality applications can utilize visual markers, as e.g. in [23], or image recognition without markers, as in Nokia Point & Find[4]. Although most of the mobile augmented reality applications utilize the screen as the output channel, also mobile device integrated pico projectors have been used for augmenting physical objects, see e.g. [25].

Augmented virtuality applications are characterized by building dominantly on a virtual world, which appears also in the core of the UI design. The virtual world incorporates elements derived from real world data, for instance for re-playing the user's path in virtual world with an avatar [11]. Jang et al. [10] have investigated the possibilities of overlapping the virtual and real world, and created a representation of an indoor space in the virtual space. The user's movements in the real world are tracked and represented with an avatar in the virtual world. The "Can you see me now?" pervasive game utilizes similar approach for a city, which has been modeled to a virtual world [3]. In [10] the avatars can be viewed with a mobile phone application.

Research on mobile mixed reality has typically concentrated on augmented reality applications. User research comparing augmented reality and augmented virtuality UIs is, to the best of our knowledge, non-existent.

User Experience with Mobile Mixed Reality

Most of mobile mixed reality research has concentrated either on developing and evaluating an application or an interaction concept, and the published research focuses typically on proof of concept level case studies with prototypes. The user evaluation of MR prototype systems have altogether been quite scarce, as revealed by Dünser et al., who reviewed AR research articles published between 1993 and 2007. It was found that in the total number of ACM and IEEE AR research publications, only 10% included a user evaluation when informal methods were taken into account [6].

User experience (UX) research has gained much attention among HCI research during recent years and expanded the horizons beyond traditional usability research [13]. UX research highlights that product qualities should be investigated in a larger than just instrumental framework. In addition to utilitarian aspects, also hedonic aspects play a significant role in the holistic experience [7]. Among professionals in the domain, the concept of UX is generally perceived to be dynamic, context-dependent and subjective [12].

[1] www.layar.com
[2] www.wikitude.org
[3] www.google.com/mobile/goggles
[4] betalabs.nokia.com/trials/nokia-point-and-find

The user experience aspects of mobile mixed reality applications have been little examined except of the research done by Olsson and colleagues. In [19], five different mobile AR scenarios were evaluated in an online survey by 260 respondents. The central positive perceptions included the utilitarian aspects – ease of information retrieval, and saving time and effort. Negative perceptions included the fear of information overflow, and the concern that virtual reality would take away the authentic, concrete real world experience and alienate the user from it. In addition, privacy concerns and the user's desire to control the visibility of the self-created content has been pointed out, e.g., in Vaittinen et al. [26], who conducted a diary study on creating (imaginary) MR annotations. In [22], Olsson & Salo present the results of an online survey where the experiences with existing MMR applications were charted, and reveal that curiosity and interest towards (new) MR technology were the key drivers for trying out the applications. They also report that although the overall perceptions with the technology were rather positive, the experiences with the applications varied between the individual users, being often rather contradictory with each other. Olsson et al. have concluded that MMR applications have not yet reached their full potential [22].

Positioning and Objectives of Our Research

Our research differs from prior art on MMR UX [5, 18, 19, 21, 22, 26] in the research methods as well as in the focus, which in our case has emphasis in comparing augmented reality and augmented virtuality UI designs.

Our research is influenced by the research approach described in [29], research by design. We investigate the phenomenon by designing and creating artifacts (here, MMR concept designs and UI simulations), which the study participants evaluate and interact with. The evaluation of prototypes with emerging technologies has been found to be beneficial in recognizing faults and risks in design, and Anastassova et al. report on gaining richer data if the evaluation is done in the authentic environment in the field rather than in a laboratory [1]. We use mixed-fidelity prototyping, meaning that the prototype is high fidelity in some respects and low fidelity in some others [16]. In our case, the prototype resembled wizard-of-Oz prototyping, which is regarded to suit well situations where the implementation is demanding [15]. We aimed to create an illusion of functional prototype by bringing people to use the simulation *in situ* in the city center.

De Sa and Churchill present how they have used different fidelity level prototypes in their mobile mixed reality research, reaching from paper prototype to an implemented high fidelity prototype [4]. With the exception of [4], earlier publications on MMR UX design have applied methods that are often disconnected from the context of use. In prior art, [19, 21, 22] only online surveys are used, which in our research has been a complementary research method. The findings of [18] are based on focus groups, and [5] present concept design prototypes, which however have not been evaluated in field conditions. In [20], Olsson et al. conducted interviews in a shopping center context with a trivial physical object representing of an "omnipotent" futuristic MAR device, which is very different to our UI simulation approach. In respect to the earlier research on MMR UX, our research contributes by offering insights due conducting the user study in real life settings with an interactive UI simulation used in a real world user context (city center).

We conducted two user studies, referred further as Study I (field study) and Study II (online survey), which resulted in a vast amount of data for analysis. The objectives of our research of MMR UX were

1) to investigate if there were differences in user perceptions when shifting the balance from augmented reality UI towards augmented virtuality UI, and
2) if found, to chart what was perceived as potential strengths and weaknesses of each approach from the UX point of view.

PROTOTYPE AND CONCEPT DESIGN

The concept design included two UI styles, where the first was based on augmented reality camera view (referred later also as Live view, as in the prototype UI), and the second UI was created on top of the virtual world, which presented a 3D model of the city center. These two UIs were identical from their layout and interactivity, and were shown on a single mobile phone to the test participant. Examples of UI layouts are presented in Figures 2 and 3.

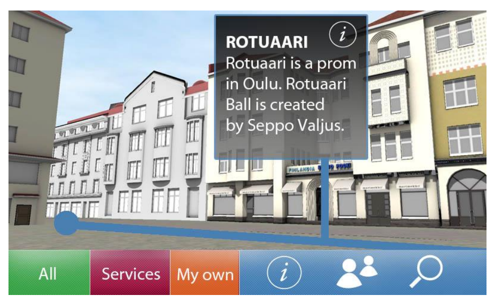

Figure 2. Mixed reality UI layout with location-based information attached on the 3D city view.

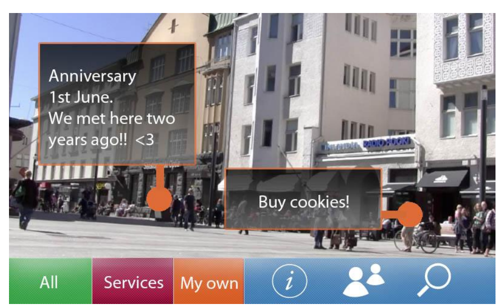

Figure 3. Examples of private content seen in the UI layout accompanied with a live view of the town square.

The virtual world based UI design utilized the 3D model of the city, which had been created from a point cloud gained from scanning the streets and buildings with a laser scanner from the ground level. The textures to the buildings have been created from photographs. Altogether the 3D model contained an area of nine blocks at the city center of Oulu, Finland, in May 2012.

The concept design included MMR view of different kind of textual annotations or information text boxes, as illustrated in Figures 2 and 3. The user was able to switch between different information views by tapping the tabs on the bottom or the screen. The tabs included commercial information (*Services* tab), own (imaginary) annotations (*My own)*, city information (*i*) and social information tab, which presented annotations created by other people. In addition, all content types could be presented in one view (*All* tab). As recommended in [5], we included color coding for different categories.

The prototype UI was an interactive touch screen simulation, and the users could select different information content as well as switch between 3D model and camera based view, which both included identical UI content (annotations, tabs). The camera based live view was not a real time implementation, but was built on a video shot on the spot where the study was conducted. However, when conducting the study, the moderator acted according to a well-planned study scripts, and in the beginning, guided the user in the panning gesture so that the video view was (surprisingly well) synchronized with the gesture when the user viewed the city scene further down the street. After that, the users performed the tasks by directing themselves (and the device) to a certain direction (Figure 4), and while they focused very much on commenting the content, they neglected to pay attention to the difference between the video and real time view. The moderator took care that the user stood towards the pre-recorded video scene. We witnessed that this created surprisingly well an illusion of a functional prototype. The study was conducted on a pedestrian street, with similar lighting conditions as when the video was shot.

Figure 4. User study participant using the device.

USER STUDY SET-UP – FIELD STYDY (STUDY I)

Equipment

The UI simulation was an Android-application made with the Eclipse version 3.7.2. The mobile phone used in the study was an LG Optimus 3D P920, which was used in 2D mode (also autostereoscopic 3D mode available with the model). The phone had a screen resolution of 800x480. The image of the 3D scene was a screenshot taken from realXtend Tundra 2.3.3 running the Oulu city 3D scene. The video from the 3D scene was captured in Linux OS with the video capturing tool GLC. The visual appearance of the application was created with the Adobe Photoshop Creative Suite 6.

Participants

We conducted field study interviews with 35 participants (20 male, 15 female), aged between 16 and 63 (average 31) years. Seven were tourists or other visitors, who were not familiar with the Oulu city center, but most (28/35) were local residents living in the city or its surroundings. Participants had varying backgrounds, and were recruited through a mailing list of a city-wide research volunteer center, complemented with university mailing lists, personal networks, and *in situ* recruiting.

All 35 participants had a mobile phone, all with a camera and 63 % with a touch screen. Almost all participants had experience with Google street view maps: 83 % were using them and 14 % had at least tried. Car navigators were also commonly utilized among the participants: 57 % reported using them regularly and an additional 23% had tried them. Altogether 63 % had experience on using the map application on a mobile phone. A total of 66 % played or had tried computer games involving moving in a 3D virtual world. Only 9 % had tried augmented reality applications and, in addition, 37 % had heard about them. The experimented applications were Google Goggles, Wikitude and Layar, but no one was using them regularly.

Tasks

Field study was carried out at the town square, exactly at the same place which had been used in for creating the UI simulation. Each test session lasted about half an hour. The study consisted of the following flow:

a) Written survey of the background information
b) Interactive tasks with the (simulated) mobile application, see tasks in Table 1
c) Assessing user perceptions with location-based annotations
d) Written end survey

Tasks	Steps	Asked questions/ Notes
1) Trying out the phone and the (simulated) application	1) Watching the *actual live view* through the camera	For getting used to the device and making sure the participant is able to see the content on the screen
	2) Watching the *video* made from the 3D model view and panning the device simultaneously following the movement of the video	The researcher was advising the user to point with the device in the right direction. (After starting the video, most participants panned the device spontaneously)
	3) When the video was stopped, watching *still 3D image*	If the user did not stop moving the device spontaneously s/he was asked to do it. Asked questions: How does this appear to you? Where this could be used?
2) Interacting with and evaluating the live-based and 3D model based UI designs	1) Pressing "Live" label in the 3D based UI, watching the live view based (still) UI	Comments? Feelings about the UI? How and where it could be used?
	2) Pressing "3D", watching the 3D model based UI view	Comments? Feelings about the UI? How and where it could be used?
	3) Pressing content type labels, watching the content views in both live and 3D UI modes	Comments? Assess the clarity, pleasantness, informativeness and utility

Table 1. Steps of the study flow and questions asked during the interacting with the simulated test application phase.

After completing the tasks where they interacted with the simulation on the mobile phone, the participants were asked about annotations they expected or would like to see on their own device. These findings are out of the scope of this paper, and instead are reported in [28].

Finally, participants were asked to fill in an end questionnaire where they selected the most pleasant UI, rated the UI layouts from different perspectives on a 7-point Likert scale. They were also asked to write down perceptions on for what purposes and situations different UI layout modes suited the best, and comment about the usage posture and the pros and cons of the two UI layouts.

The participants were encouraged to think aloud during the study, and the study sessions were recorded on video. Most of the data from field study sessions was qualitative but was completed with quantitative ratings from structured enquiry forms and survey questions. The analysis of qualitative data involved transcribing the content, constructing affinity walls and thematic coding.

USER STUDY SET-UP – ONLINE SURVEY (STUDY II)

In addition to the field study, an online survey was created with the SurveyMonkey tool. The participants were presented with mixed reality views consisting of live view and 3D view UI layouts. In the online survey, the UI views were shown as screenshots, and by using the same UI layouts as in the field study. The users were asked about their opinions and preferences regarding the suggested UIs, perceptions of remote and *in situ* use, content types, and content creation and sharing. Partially the results of the online survey are reported in [28], as they fall outside of the scope of this paper.

The online survey was visited 149 times and completed by a total of 111 participants. It is to be noted that because of the drop-out rate, the number of participants answering each question differed slightly. In the following, the number of participants is reported according to number of respondents with the specific question.

The majority of the participants belonged to age groups 30–39 (32 %) and 18–24 (27 %). Over half (58 %) were female. The majority of the participants (94 %) lived in Finland and 32 % lived or worked in Oulu. Everybody had a mobile phone and over 90 % had a camera in their phones. A total of 31 % reported playing 3D virtual world games and 20 % had experimented such games. Altogether 87 % of the participants had used Google Street View application. When asked about mixed reality applications, 12 % had used, 18 % experimented and 36 % heard of them. (Age was asked in the survey in an age group format, whereas in the field study the exact age was asked. Therefore the form of presenting the age varies in quotes from the participants.)

RESULTS

First impressions of the 3D model in the field study

After they were given the phone to try out its live camera view, the users were shown the plain 3D model view with no menu or other annotations on top of the picture, and asked the first impressions and how the 3D model scene could be utilized. According to the researcher's observations in the field, at first the users seemed to believe the application was really functional and interactive in the sense that it was responding to the user's movements. After watching the video with the device and when the picture turned into still mode the simulated mode of the application became clear. At this point, it was also explained to the participant that the application was just a simulation and it was made to give the impression of being interactive. However, after the first impressions it was already easy for the most to imagine how the actual working prototype would function.

After seeing the video prototype, most of the participants' comments were positive. The 3D city model was well recognized to present the same location, and it was generally considered clearer and more usable than the plain camera view. The sunny weather caused some difficulties in seeing the content of the camera based screen e.g. due to shadows, but the 3D model picture was easier to see on such conditions.

"The 3D model view is more usable in sunny weather. The 3D model is more natural to use." (female, 24).

Although such functionality was not simulated, it was recognized that the 3D model based view could also work as a laser eye to provide more information than the physical reality view:

"Wow! like in movies. You can use [the virtual model] if you want to see further [places]." (female, 23).

However, eight (8/35) users had the first impression that the 3D model was not realistic or recognizable enough to be usable, and the value to use 3D based view was hard to perceive. Real camera view was also considered more interesting because of its detailed, vivid and dynamic nature.

Comparing the camera-based and 3D model UI views

The camera view based UI was the most appealing for most of the participants in both field and online study, see Figure 5. In the field study, 69 % selected the camera view based option and 26 % the 3D model based UI as the most appealing. Two participants could not say their preference. In the online survey, 84 % of the respondents preferred the camera view based user interface.

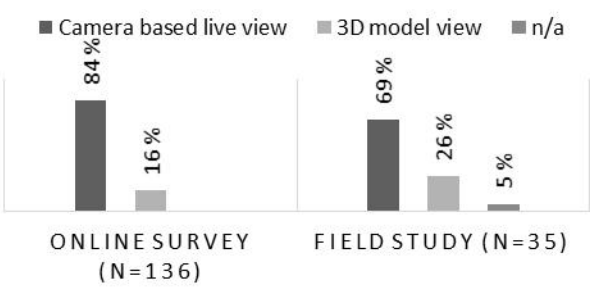

Figure 5. Preferred UI view - Online survey versus Field study

Field Study Responses

The most appealing feature of the camera view based UI was the **realism** it provided**,** see Table 2. The camera view was perceived to be more immersive and the experience with it more personal than with the virtual world view.

Positive comment	**N of users**
More naturalistic and real	10/35
Associating with the environment is easier	6/35
Clearer and more aesthetic	6/35
More vivid, interesting and detailed	4/35
More up to date	2/35

Table 2. Positive comments about the camera based view and number of mentioned users.

The main reason to select the 3D as the most appealing was **clarity** (see Figure 6). Altogether 26 % of the participants stated that the 3D model was better because of the shadows, people or other moving elements did not intrude the view. The clarity also stood up when the best use case or purpose for 3D UI was asked (see Figure 7). Altogether 26 % suggested it suits best a situation where a clearer picture was needed:

"*When there is traffic jam, rush, roadwork or similar thing that blocks up the visibility.* " (male, 26).

"*For people with a weak eye sight, it is clearer.*" (female, 18).

Two participants suggested that some kind of combination of these two user interfaces would be ideal, and enriching the plain 3D model view with elements of the physical reality was seen to make it more realistic.

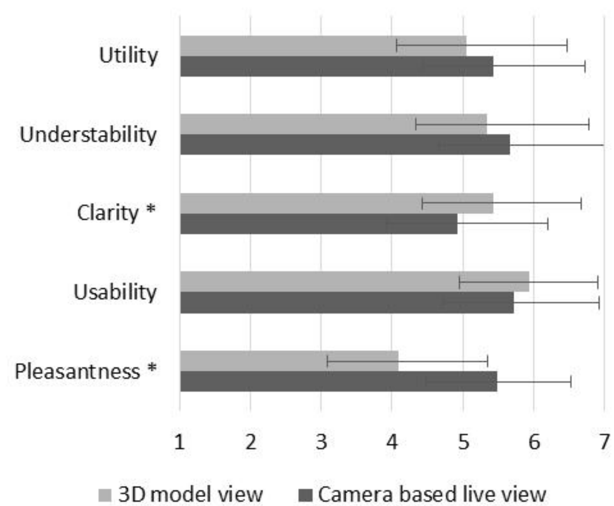

Figure 6. Study I: Assessing the 3D view based and Camera view based User Interfaces, averages (Likert scale 1–7) and

standard deviations. * Statistically significant difference p < .001

A statistical analysis supported the interview results. A Wilcoxon matched pairs signed rank analysis indicated that there were significant differences for pleasantness ($z = -3.6$, $p < .001$) with camera based being preferred, and for clarity ($z = -3.4$, $p < .001$) with 3D based being preferred.

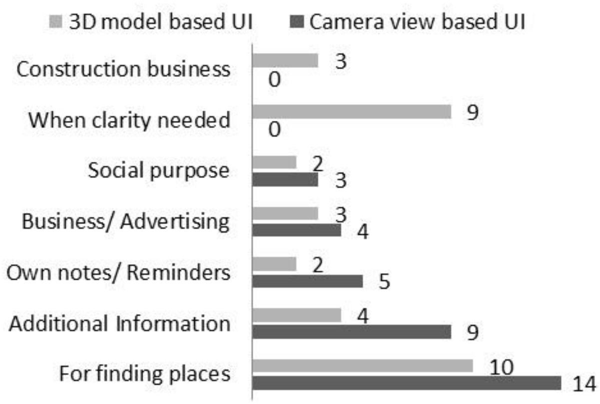

Figure 7. Study I: Free text field answers on 'For what purpose would the camera view UI / 3D model UI be best suited? '

Survey responses

The online survey supported the *in situ* results in many ways, see Table 3. In the survey, 65 % of the respondents saw benefits and 46 % found drawbacks in the camera based UI. When assessing the UI created on top of the 3D modeling, 61 % of the users found drawbacks and 51 % benefits. The findings are summarized in Table 3.

Camera based UI	**Benefits 65 %**	More realistic
		Easier to associate with the environment
	Draw-backs 46 %	Battery consumption
		Malfunction of the application
3D model based UI	**Benefits 51.4 %**	Clarity
		Conceiving the space is easier
		Remote usage
		Better ergonomics
	Draw-backs 61.3 %	Associating 3D model with reality
		Slow processing with a mobile phone
		Updating the model

Table 3. Mentioned benefits and drawbacks of both UI:s in the online survey.

Both UIs had their strengths and sometimes choosing one over the other was impossible:

"It depends! I choose A if I am pedestrian, but definitely B if I am driving. […] It completely depends on the context! If I am on vacation, visiting options, if I am on business, parking driving info..." (female, 30–39).

In addition, combining of the camera view and 3D model got support from some respondents:

"Probably most usable of these would be some sort of combination. The user could change the opacity of the camera view layer and move continuously between live and 3D view" (male, 25–29).

In the survey responses, the drawbacks reflected the users' previous experiences with augmented reality applications or mobile devices in general. Especially the anticipation of the battery consumption or malfunction of devices derived for previous unsatisfactory experiences with the devices.

User's Posture

While executing the field study, the posture of the user with the device was observed. At first, all the participants pointed the device correctly according to the instructions, followed the movement of the video and looked at both user interfaces with holding the devices up in front of their eyes like watching through the camera viewfinder. However, after a while, when proceeding with the test, moved the device into the lower position. Some asked if they could do this and some did it spontaneously.

Also when asked about the usage position the majority (89 %) of the users in the *field study* would have wanted to be able to use the device with their hands down. Here, 57 % said this was more ergonomic and natural position and hands do not get tired. A better possibility to observe the surroundings was also mentioned by 23 % of the users when validating the reason to use the device hands down. The social inconvenience with using the device was also raised up several times. More specifically, using the device unobtrusively was important for many. Altogether 26 % of the participants impressed that by holding the device hands down, the application can be used socially comfortably:

"The other way of using the device looks silly" (female, 32).

"*It doesn't look like I want to take a photo or something, that I am a tourist"* (female, 26).

While the hands down position was clearly the most desired mode for using the device for most users, some participants pointed out that using the camera in that position and the interaction metaphor of looking through a magic lens to see additional information would not work in that posture. Therefore the 3D model based UI was seen as more usable for unobtrusive usage. This was seen possible when the camera would not be in an essential role for displaying the content but the position of the device was calculated by other means. Moreover, the possibility to pan the 3D view through touch gestures rather than changing the whole posture was appreciated by the users.

In the online survey, the usage position was also pointed out when the participants were asked to point out drawbacks and advantages of the camera based UI. The same themes were raised in the survey as in the field study responses. Besides the issue with ergonomics, another disadvantage, the social inconvenience, was pointed out:

"The current cell phone technology forces the user to hold the device in an ergonomically bad position when using the camera. In addition, I have noticed in practice that it causes socially uncomfortable situations when people around you think you are photographing them" (female, 30–39).

The ability to keep the device down while using the application was seen as an advantage of the 3D model based UI:

"You don't have to point the camera towards the object, so you are possibly able to use the device without drawing attention" (female, 30–39).

In addition, another disadvantage of the hands up usage came up in the online survey, as holding the device still was expected to be difficult:

"When using the live view, hand is moving all the time and the augmented reality information blinks and moves too constantly. Also the sun reflects and you cannot see properly when holding the device upright position" (female, 30–39).

This citation reflects the respondent's earlier experiences with MMR applications.

DISCUSSION

Virtual vs. Real in UI Design

Although our research resulted in numerous similar findings related to mobile mixed reality applications in general, there were some aspects where we witnessed clear differences in the users' perceptions on the camera based UI and 3D model based UI, representing the augmented reality and augmented virtuality UI design approaches, respectively. We were somewhat surprised that although the 3D model was of very high quality, it still caused some confusion with users experiencing difficulties to orientate themselves with the view. The immediate and non-artificial nature of the camera view clearly improved the immersion with the mixed reality application and made it feel more personal and less game-like. Even as the first impressions with the 3D model were mostly positive, the majority of users selected the camera based view as their favorite of the two UIs.

However, the 3D model based UI had its advantages. Here, the visual clarity was one of the key features – shadows or crowds of people did not distract the view. People having earlier experience with MMR had insight to their usability problems and pointed out that the flicker typically associated with MMR applications could be overcome with a virtual world based UI. In general, the choice between AR and AV UIs seems lead to the tradeoff between naturalism and realism versus clarity. We observed that visual transitions helped in associating the 3D model with the physical reality, and combining the two views could be an optimal (yet technically somewhat challenging) solution to the problem.

The 3D model based UI design was appreciated when it was seen to fulfill the utilitarian needs and expectations better. In addition to a clearer visual presentation, the ability to access the MR UI remotely and hold the device in an ergonomically better position were factors that were appreciated. Remote and *in situ* use was connected to different utilitarian needs - remote use was perceived useful for planning, *in situ* use for getting additional information.

Design recommendations

On the basis of the findings, the following recommendations for designing MMR application were derived:

Allow users to select between a camera based and virtual reality based user interface according to the situation

Both studied user interfaces have their ideal use cases and ideally, the user should be able to switch between them according to the situation. For instance, the 3D virtual model based user interface may work better in a dark or shadowy environment, or when the user is moving fast. The camera based UI may be favored when the user is interested in seeing detailed information of the surroundings.

Allow hybrid use of the UI versions

One of the main drawbacks of the 3D model based UI was identifying the view of the virtual world with the real physical view. Still, the augmented virtuality view would offer a clearer view of the surroundings. Enriching the 3D view with elements from the live view would help associating the 3D view with the physical reality.

Allow the user to use the device unobtrusively

For several reasons (ergonomics, the visibility of the surroundings, social awkwardness) using the device in a hands-up posture, in front of the eyes, is not comfortable. For that reason the user should be able to use the device also when not pointing to the point of interest. Here, e.g. scrolling the 3D model view manually could be an option.

Methodological Observations

Methodologically, comparing the 3D model and real life street view was easier and more authentic in the field study, and the results have more accountability. Although the test application was just a simulation, it gave users enough stimuli to imagine how the actual working application would function and how using the device in real environment would feel. On the other hand, the online survey brought up more a versatile set of suggestions, and people thought the potential use cases for the application in a wider context, such as the application use while driving a car. However, the earlier experience and knowledge had more effect on the users' answers in the survey and former bad experiences might have reflected in the survey answers. However, possible earlier experiences did not affect the survey respondent's results only in a negative way, but also helped the users to better imagine and envision the usage situations.

Limitations of the study

We acknowledge that our research is limited by the study method, and more realistic results could have been obtained if the research had been conducted with a functional application and over a long period of usage to avoid the novelty effect. However, as we wished to compare two alternative UI designs this was not an option, as such application with a virtual world based UI does not yet exist. Running a study with functional prototypes would have required significant effort even for a limited feature set. Despite of these limitations, we still believe that our findings provide useful and interesting background information for designing future MMR user interfaces.

CONCLUSION

In this paper, we have focused on mobile mixed reality (MMR) applications in urban environments and investigated the user perceptions on the UI design solutions, especially by comparing two different UI concept designs, one built on a camera based augmented reality view and one on a virtual 3D model of the city. In respect to prior art, our paper has novelty in the comparative settings of the study and in charting the user experiences in the field context. Specifically, to the best of our knowledge in the field of MMR, user studies comparing augmented reality and augmented virtuality based approach to UI design has not been conducted before.

Altogether 69% of the field study participants (n=35 in total) and 84% of online survey respondents (n=136) chose the camera view based UI more appealing than the 3D model based UI. However, the results indicate that both virtual and 3D model based UI have their strengths. Where associating the physical reality and the UI is simpler with the camera view based UI, the 3D model based UI fits some cases better. The 3D model based UI offers a clearer view which omits the disruptive elements of the real world (e.g. shadows, people). This strength may be emphasized e.g. with high traffic conditions, street constructions, or while driving. Clarity, possibility to remote usage, and ergonomically better usage (no need to hold the device up) were seen as the benefits of the 3D model based user interface. The main perceived drawbacks of the camera-based UI were the hands-up usage posture, expectedly high battery consumption, and its dependency of the circumstantial conditions such as weather, ambient light, or traffic. Moreover, the malfunctioning of the application also concerned the respondents. The identified weaknesses related to the virtual world 3D model were the difficulties in associating the reality with the virtual 3D model, and concerns related to the data connection and infrastructure – a slow processing of the 3D model with a mobile phone and the (potentially missing) updates of the model.

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