Comparison of Wearable Optical See-through and Handheld Devices as Platform for an Augmented Reality Museum Guide

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Abstract: Self-service guides are a common way of providing information about artworks exhibited in museums. Modern advances in handheld mobile applications and wearable optical see-through devices that use augmented reality offer new ways of designing museum guides that are more engaging and interactive than traditional self-service guides such as written descriptions or audio guides. In this study we compare wearable (smart glasses) and handheld (smartphone) devices as a platform for an augmented reality museum guide. We have developed a museum guide for both a smartphone and smart glasses that can identify artwork, direct the visitors' attention to specific details in it, as well as engage them through a game. The platforms are compared based on participants' preference feedback and game performance, and are also evaluated by a coordinator from a collaborating museum. We conclude with a discussion of potentials of these platforms as augmented reality museum guides and suggest promising future work.

1 INTRODUCTION

While written descriptions or audio guides are common ways of providing self-service guidance in museums, they are limited in the way information is provided. Audio guides, for instance, are limited to only listening, and often, the viewer might not know which part of the artwork the guide is referring to. There is also often a lack of elements that would stimulate visitors to interact with the artwork. Currently, a new trend of smart devices has evolved that has the capability to promote active participation for visitors of cultural heritage sites. Devices such as smartphones or smart glasses allow visitors to get more involved in the museum experience. Furthermore, recent developments in new media such as games, augmented and virtual reality, and interactive storytelling, have brought new effective ways of experimenting with immersion in virtual storyworlds (Lombardo and Damiano, 2012).

With these advances in both smart technologies and immersive media, several researchers (Chang et al., 2014; Tillon et al., 2010) have found new ways of addressing limitations of traditional guides. By using tablets and smartphones, their studies developed handheld augmented reality (AR) guides that superimposed virtual descriptions and graphics on artworks. Besides the handheld guides, there have also been advances in wearable optical see-through technology (smart glasses) which have introduced a different approach towards overcoming these limitations. Both smartphones and smart glasses have advanced functionalities such as camera, audio, image display, and touch input, which allow for new exciting ways of presenting cultural heritage narrative content and making it interactive. These platforms have their pros and cons. Handhelds are very accessible since most people own a smartphone, while smart glasses are hands-free. They both have the capability to be used as self-service museum guides, however there has not yet been a study that has compared them in this context.

This work therefore aims to investigate this gap and evaluates which of the guides is more intuitive to use, provides better guidance and involves or engages visitors more in the museum's artworks. We developed a museum guide for both platforms that can direct visitors' attention to where they should look at in an artwork while a narrative is presented. Furthermore, the guides also include a game where users have to match clues shown on the device display to that of the physical artwork. To compare the two platforms, an experiment was set up, where participants evaluated the guides in questionnaires and semi-

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structured interviews. In addition, the participants' game performance was logged to evaluate how involved or motivated they were during the experience.

This paper presents the following main novelties and contributions:

- A comparison of smartphone and smart glasses as devices that can be used to develop AR self-service museum guides.
- A discussion of how to develop AR museum guides for smart glasses.
- A discussion of how to design and implement an AR game that works on both handheld devices and smart glasses.

The paper continues with an in-depth look at related work in Section 2. In Section 3, we describe how the museum guides were implemented, and how they were compared in an experiment. Results from the experiment are presented in Section 4 and discussed in Section 5. Lastly, we conclude on our findings in Section 6.

2 RELATED WORK

AR displays can be categorized into different types, which include head-mounted, handheld, and spatial displays, etc. In their paper, Bimber and Raskar (2006) state that the augmented image can be formed at different places along the optical path between the eyes and the physical object. For the smartphone, the image is formed on a handheld display, while for the smart glasses, it is generated on a wearable head-mounted display. In both cases, the image is generated on a plane. To combine the augmented graphics with the physical scene, the smartphone uses a technique called video-mixing, where a live video stream of the physical scene is combined with the rendered augmented graphics and this combination is displayed on the screen. The smart glasses on the other hand use a technique called optical combination, where the augmented graphics are rendered and projected in the viewer's field of view, which makes the graphics appear as if they were in the physical scene. Both wearable optical see-through and handheld devices have been used in various research projects in the cultural heritage context.

Wearable optical see-through devices have been researched by Dalens et al. (2014) and Baraldi et al. (2015) who implemented computer vision methods on devices such as Google Glass to recognize paintings in real time, and detect hand gestures which visitors could use to naturally interact with the artwork. These studies however did not test user experience. Bower and Sturman (2015) examined the potential of wearable technologies, where they identified affordances such as experiencing various scenarios that otherwise would be risky or not possible (e.g. a tour in a medieval village, zooming in), raising involvement and engagement, communication, real-time guidance, feedback, and gamification.

In parrellel, handheld AR guides have been explored by Damala et al. (2008), Chang et al. (2014), and Tillon et al. (2010). Findings from these studies have shown that AR guides recieved positive feedback and helped participants to better appreciate paintings. A few participants in Chang et al.'s (2014) study however found the tablet heavy and inconvenient. It could be investigated whether wearable optical see-through devices can have an advantage since they are hands-free.

Several of the presented works were concerned with improving visitors' experience in cultural heritage settings. In order to evaluate these improvements, Othman et al. (2013) proposed a Multimedia Guide Scale that can be used to evaluate guides in terms of general usability, the quality of interaction, and learnability & control. Othman et al. (2011) also proposed a Museum Experience Scale for the purpose of evaluating the experience, where the guide can be evaluated through engagement, knowledge & learning, meaningful experience, and emotional connection. Although these scales were not tested on AR guides, they can be used as inspiration when comparing the handheld and wearable AR guides in terms of enhancing the user experience.

Engagement and active participantion with the artworks have been explored by Rubino et al. (2015) and Schmalstieg and Wagner (2007) who have included gamification in handheld AR guides. Through use of storytelling adventure games and pervasive games, their studies suggest that games are an engaging way of bringing an active role to the visitors, and thereby, increase their satisfaction during the museum experience. These studies indicate that games could also be used to evaluate the effectiveness of the guide and compare handheld AR guides with wearable optical see-through AR guides. The work presented in this paper took inspiration from several of the related studies and developed a museum guide that was used in an architectural museum.

3 MATERIALS AND METHOD

To investigate the use of wearable optical see-through and handheld AR museum guides for self-service guidance, two conditions were designed: a handheld

AR guide condition and a wearable AR guide condition. The guides were evaluated in terms of the overall museum experience they provide, visitors' involvement and engagement into the artworks, and their satisfaction with the guidance. Our assumption was that the handheld AR guide would be perceived as more intuitive and easier to use. On the other hand, because the augmented graphics in the smart glasses are directly in the viewers' field of view and appear as if they were in the physical scene, we assumed that the wearable AR guide would provide a more engaging experience and involve the visitor more with the artworks.

A game was included to assess how easy visitors would find it to interact with and explore the artwork. Our assumption was that a high game performance with a good score and a short completion time would imply that the visitors were engaged and the guide was intuitive to use and interact with, while low performance or long completion time would imply low engagement or less intuitive interaction.

3.1 AR Museum Guide Design

The design of both wearable and handheld AR guides consisted of several parts: interactive storytelling and gamification, tracking the artwork, and superimposing the graphics. Furthermore, two artwork collages were used, which were part of the exhibition "Fatamorgana: Utzon meets Jorn" at the Utzon Center museum in Aalborg, Denmark. The two collages can be seen in Figure 1, where two men are surrounded by their inspiration from each other's field. Artist Asger Jorn is on the left and as can be seen, images in his collage are of architectural buildings. Architect Jørn Utzon is on the right, surrounded by artistic images.

Figure 1: Asger Jorn collage (left) and Jørn Utzon collage (right).

3.1.1 Interactive Digital Storytelling and Gamification

The objective of the museum guide was to present information about Jørn Utzon, Asger Jorn, and their inspirations from art and architecture, which inspired them to collaborate on designing Silkeborg Museum for exhibiting Asger's art. In the actual exhibition, there was a big text panel describing the two men and the images in the collages were given numbers. Visitors could then read the description to get a general understanding of each of the collages, as well as read the names of the images based on their numbers in a small text panel on the side of the collages. All information was available in both Danish and English because the museum had both Danish and international visitors.

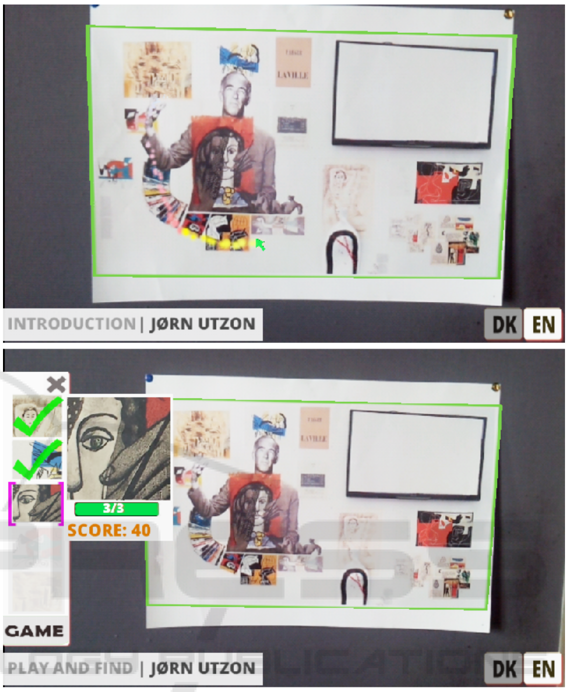

Figure 2: The introduction stage with the pointer directing attention (top) and the game stage with clues in the game panel (bottom).

Our guide system used this information and enhanced it by adding audio, visuals, and interaction. To present the guidance, a narrative was created, which consisted of three stages: introduction, exploration, and game. The structure of the narrative was inspired from the complete graph narrative structure, where the visitor can access information and parts of the narrative in any desired order (Ryan, 2001). Once the visitors approached the collage, they could use the device as a guide. They would start by selecting the language to be used during the guidance and afterwards, the introduction was played in form of audio with a pointer to guide the visitors' attention to the element being presented. The introduction covered the description information from the big text panel, and when it was finished, the guide proceeded to the second stage – the exploration. Here the user could interactively select images in the collage for more specific information that was inspired from the small text panel. In the corner of the guide display, there was a

"Game" button, which when clicked caused the user to go to the third stage – the game, as seen in Figure 2.

The game involved matching the clues displayed in the game panel to the images in the collage. These clues were small images cut out from five of the collage's images, where the objective was to match the clue and image correctly within three attempts. If the visitor matched them correctly on the first attempt, they would get 20 points, on the second attempt 13 points, and on the third attempt 7 points. Thus, if all clues were matched correctly on the first attempt, the visitor would get 100 points. Every clue had corresponding audible information that related to the images in the collage and was inspired by the small text panel. This information was played when the clue was presented for matching. Audio feedback was given when the visitor found a match or made a mistake. Upon completing the game, information that was otherwise not displayed in the collages was narrated to the visitor as a reward. For Asger Jorn, the visitor would learn that he invented three-sided football, and for Jørn Utzon, they were told that he wanted to be a sculptor, but was convinced by his uncle to become an architect.

3.1.2 Augmented Reality Setup

The equipment (see Figure 3) used for the handheld AR guide was a Samsung I9100 Galaxy SII with a display size of 4.3 inches, screen resolution of 480 × 800 pixels, an 8 megapixel camera, and a weight of 116 grams. For the wearable AR guide, a set of Epson Moverio BT-200 smart glasses was used, which had two LCDs, each with the size of 0.42 inches, a screen resolution of 540 × 960 for each eye, a field of view of 23 degrees, a VGA front camera, and a weight of 88 grams. Users interacted with the smartphone via touch directly on the display, while the smart glasses had a touchpad connected. The interaction mechanism for the touchpad was similar to that of the smartphone, however the display and the touchpad were two separate units. Both devices ran on the Android 4 operating system, which allowed for the guide to be developed as an application with the 32-bit Unity 5.3.1f1 game engine. Unity made it possible to build the application on Android and also to use the Moverio SDK plugin for the smart glasses.

The Vuforia SDK v5.0.10 plugin for Unity was used to track the collages. No additional fiducial markers had to be set up in the exhibition because the collages were used directly as tracking markers. Tracking was possible by using the frontal camera on the glasses and the back camera of the phone. When the collages were not in the camera's view, a message "Lost picture..." would be displayed at the bottom of the guide's display. Once the camera was tracking one of the collages, the application would play its content. If tracking was lost again, the application would simply pause until tracking was resumed. To enable the system to recognize the two collages, they were uploaded to Vuforia's Target Manager, where features were detected in the images and stored in a database. Therefore, the guide was able to automatically identify the two physical collages via its camera, and superimpose the augmented graphical content on them.

Figure 3: Platforms for the AR guide: Epson Moverio BT-200 smart glasses connected to the touchpad and Samsung Galaxy I9100 SII.

3.2 Experimental Procedure

To compare the smartphone and the smart glasses AR guides, an experiment was designed as a within-subjects experiment and conducted at Aalborg University, where the collages were exhibited to simulate the museum setting as shown in Figure 4. 34 participants, 20 males and 14 females, aged 21 - 28 (M = 23.35, SD = 1.86) were tested. All participants had previous experience with touch mobile devices, while none of them had experience with smart glasses. 47% stated that they had used traditional museum guides during their museum visits. 38% of the participants had normal eye sight and did not use prescription glasses or contact lenses.

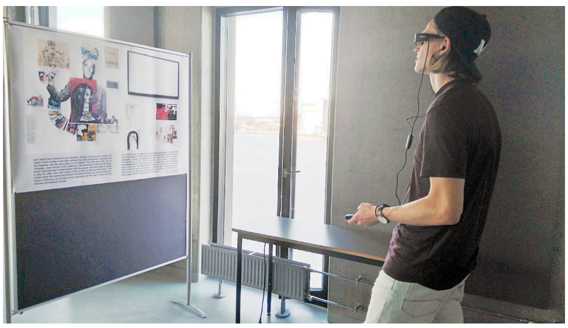

Figure 4: Test setup.

Each test session started with a short demographic questionnaire to learn about participants' background and their experience with museums. This was followed by instructions on how to use one of the smart AR guides, after which the participants used it to understand either Jørn Utzon's or Asger Jorn's collage, as shown in Figure 4. They then got instructions for the other guide before trying it on the second collage. By pseudorandomizing the order in which participants tried the smart AR guides and experienced the collages, bias was prevented. The guidance presented in the device had three stages. An introduction that presented the collage. An exploration stage, where participants exploratively interacted with the separate images in the collage by clicking to hear more information. After clicking on a minimum of five images, they could move on to the game stage, which consisted of matching clues displayed in the guide's graphical user interface to images in the collage.

During the three stages, the guide logged data in a file for assessment, which included how much time each participant spent completing each of the three stages, how many images they clicked in the exploration stage, and their score from the game. After going through all stages for each smart AR guide, participants filled out a questionnaire, where they evaluated their experience with that guide on a seven-point Likert scale. The topics of the evaluated questions were inspired from the Multimedia Guide Scale and the Museum Experience Scale proposed by Othman et al. (2011; 2013), as is shown in Table 1. Lastly, a short semi-structured interview was conducted to get more insight in the participants' experience.

Besides the experiment, the smart AR guides were presented to the exhibition coordinators at the museum to get some insight into which smart AR guide they felt worked well for the exhibits. Their feedback was important to evaluate the guides in a practical setting and assess whether this new technology could potentially be used for their exhibition professionally.

4 RESULTS

4.1 Questionnaire

Ratings obtained from questionnaires were plotted in boxplots shown in Figure 5, which also present the means. These ratings were statistically analyzed using a two-tailed Wilcoxon signed-rank test, and correlations between them were calculated using Pearson's product-moment correlation. In addition to responses from the questionnaire, feedback was obtained from semi-structured interviews. This was used to better understand the results from the questionnaire. The

Table 1: Questionnaire to evaluate both smart glasses and smartphone as museum guides (7 point scale: 1. Not at all, 7. Very much).

ENGAGEMENT
Q1: To what extent did the guide engage you to the exhibit?
Q2: To what extent were you experiencing the exhibit, rather than just visiting it?
Q3: To what extent did the guide connect you with the exhibit?
GUIDANCE
Q4: To what extent did the guide direct your attention where to look in the exhibit?
Q5: To what extent did the guide help you understand the exhibit?
INTERACTION & INTUITIVENESS
Q6: How easy was the guide to use?
Q7: How easy was it to learn how to use the guide?
Q8: How intuitive was it to interact with the guide, e.g. clicking buttons and clicking on images?
GAMIFICATION
Q9: To what extent did the game in the guide involve you in the exhibit?
OVERALL SATISFACTION
Q10: To what extent were you overall satisfied with the guidance the guide provided?
Q11: If the guide was available for your next museum visit, to what extent would you like to use it?

Wilcoxon signed-rank test analysis of the ratings (see Table 2) showed significant differences between the smartphone and the smart glasses for how easy the guides were to use (Q6: $p = 0.0096$) and how easy it was to learn how to use the guides (Q7: $p = 0.0090$) in favor of the smartphone guide. Similar results could also be found in the interviews, where seven partic-

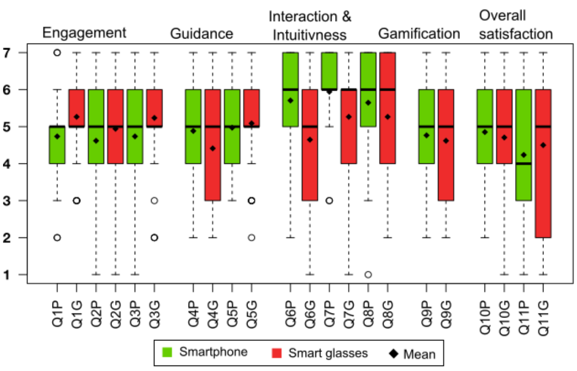

Figure 5: Smartphone and smart glasses ratings for Q1 to Q11 (P = smartphone, G = smart glasses).

ipants mentioned that the smartphone was easier to use and focus on. Smart glasses, on the contrary, had a higher rating in engagement (Q1: $p = 0.072$, Q3: $p = 0.075$), although no significant difference was found.

Table 2: Ratings from all participants compared in Wilcoxon signed-rank test (* = p <0.05).

	Smartphone		Smart Glasses		
Question	*M*	*SD*	*M*	*SD*	p-value
Q1	4.74	1.16	5.27	1.19	0.072
Q2	4.61	1.39	4.94	1.37	0.31
Q3	4.74	1.56	5.24	1.37	0.075
Q4	4.88	1.53	4.41	1.76	0.18
Q5	4.97	1.09	5.09	1.22	0.57
Q6	5.71	1.36	4.65	1.63	0.0096*
Q7	5.94	1.01	5.27	1.40	0.0090*
Q8	5.65	1.32	5.27	1.76	0.13
Q9	4.77	1.42	4.62	1.65	0.76
Q10	4.85	1.33	4.71	1.62	0.58
Q11	4.24	1.81	4.50	2.14	0.59

During the experiment, it was observed that females and males had divided opinions about the two smart AR guides, and therefore the statistical data was split for genders. Results showed that females did not find any of the guides significantly different from the other. However, males reported differences on intuitiveness and found it significantly easier to learn how to use the smartphone (Q7: $p = 0.049$). Males also felt that the guide presented on the smart glasses engaged them in the exhibit more than the smartphone (Q1: $p = 0.017$, Q2: $p = 0.022$, Q3: $p = 0.0064$).

There was no significant difference between the two smart AR guides in the ratings on guidance, gamification, and overall satisfaction. Pearson's product-moment correlation, however, showed that the participants' ratings on whether they would use the guide if available in the museum, had a high degree of correlation with ratings on engagement (Q1: $r = 0.61$, Q2: $r = 0.63$, Q3: $r = 0.59$), understanding (Q5: $r = 0.56$), gamification (Q9: $r = 0.52$) and the overall satisfaction with the guide (Q10: $r = 0.75$).

4.2 Performance and Time Data

Interaction, game score, and time data was analyzed using a two-tailed two-sample t-test, and a Fisher's exact test was used to analyze how many clues participants matched correctly in the game. As can be seen in Figure 6, participants took longer time interacting with the smart glasses than the smartphone. They spent significantly longer time during the exploration stage ($p = 0.00008$) and during the overall experience with the three stages ($p = 0.00002$). The time spent for the game stage alone was, on the other hand, not significantly different for the two guides ($p = 0.055$), and the introduction stage was fixed and took approximately 60 seconds for both. Similar to the questionnaire, these significant time differences also show that the smartphone was easier to use and interact with. In the exploration stage (see Figure 7), participants clicked ten images on average when using smart glasses, which was significantly more compared to the smartphone where only six images were clicked on average ($p = 0.0002$). This shows that participants were more engaged when they used the smart glasses to interact with the collage.

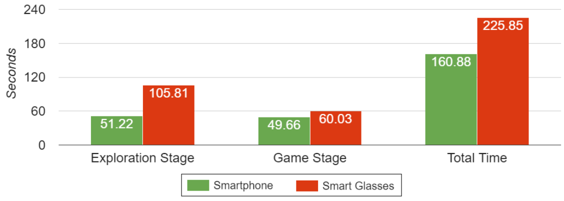

Figure 6: Time spent using the guides. Introduction stage was fixed and took 60 seconds.

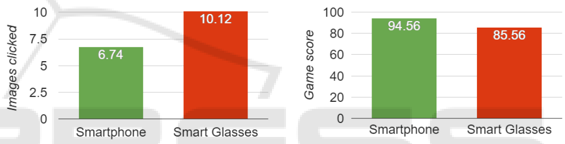

Figure 7: Images clicked in the exploration stage and scores in the game.

During the game, participants scored 94.6 points out of 100 on average when using the smartphone, as shown in Figure 7. This was significantly higher compared to the average of 85.6 points when using the smart glasses ($p = 0.0093$). Participants using the smartphone were also able to match significantly more clues in the game correctly (smartphone $M = 4.9$, smart glasses $M = 4.6$, $p = 0.044$).

4.3 Semi-structured Interview

In the interviews, participants were asked to evaluate which of the guides made the exhibition most fun. 26 participants said that it was the smart glasses, while the remaining eight said it was the smartphone. The Fisher's exact test showed that significantly more participants found the smart glasses more fun ($p = 0.043$). Ten participants admitted that part of the appeal for smart glasses was because they "are new" and that they "have not tried them before". On the other hand, seven participants said that with the smart glasses, they "felt more part of the exhibition" and "did not have to look through a secondary screen".

Despite being more engaging, the smart glasses were however found to be "heavy" as mentioned by seven participants. Six participants experienced “dizziness”, “pain in the eyes” or “headache”, and three participants felt that “it would be a problem to wear them for a long exhibition”. Similarly, participants also experienced some challenges while using the smartphone. Nine participants mentioned that it was “tiring for arms to hold it up” in front of the exhibition and five participants found the screen too small, saying that “it was hard to see the images”. However, six participants mentioned that they could “see the whole collage at once”, which allowed for better overview. This also enabled them to better follow and understand the guidance of the pointer than on the smart glasses, where as mentioned by seven, “it was easy to lose the pointer”.

In terms of which guide provided a better understanding of the exhibit, 11 participants said that it was the smartphone, six said it was the smart glasses, and 12 felt that it was the same for both guides. Overall, several participants gave positive feedback to the guides saying that “the glasses are very nice and engaging” and “the smartphone gives a lot of freedom”.

4.4 Expert Feedback

The following section presents thoughts from one of the exhibition coordinators at the collaborating museum.

A problem that he saw with the smart glasses was that the field of view was very small to get an augmented reality feeling. He mentioned that the interaction on the smartphone was better because you felt that “the frame in the picture that you clicked on is more like a button, while on the glasses the touchpad felt more like an extraneous element”. He said that the smart glasses could become something in the near future, but currently he thought that “the technology is not there yet”. He added that “everything works better on the phone”, also because it is an element that people can take with them. “There is something special about it being your own guide. People can just get a QR-code, scan it and get the app. It is cheap, easier and you do not have to walk around, looking like a sci-fi dude”.

Smart glasses felt like they were about to “fall down”, which he thought will be challenging for many people using them. He said that they have something in terms of the experience and will be seen more in the future, however he did not think they were there yet. Ultimately, he felt that the smartphone has the potential to cover part of the exhibition, however the smart glasses only have the potential if they can cover the whole exhibition. “With the smartphone, you can come with it and use it on part of the exhibition, whereas the smart glasses will have to be placed in front of the picture and people will have to put them on and off during their visit”.

5 DISCUSSION

The experiment investigated the use of smartphones and smart glasses as platforms for self-service museum guides. Five main topics were considered for evaluation: engagement, guidance, interaction & intuitiveness, gamification, and the overall satisfaction. For the engagement, responses from participants of the experiment showed that the smart glasses AR guide was more engaging than the smartphone, and participants were able to experience the exhibit, rather than just visit it. However, the expert feedback from the exhibition coordinator in the museum did not seem to show the same results. He found the smartphone to be a better guide and felt that the technology for smart glasses still needs to be developed before it can be applied in the museum. This seems to show that the context, in which the guides are considered, matters. In their current state, he saw the smartphone more applicable, accessible, and finished, but admitted that the smart glasses could have potential in the near future.

The smartphone was evaluated as better by participants in the experiment in terms of guidance and interaction & intuitiveness. This was less experienced on the smart glasses, which could have been due to the small field of view as was also mentioned by the exhibition coordinator. Furthermore, the touchpad of the smart glasses seemed more challenging and slower than interaction through touch on the smartphone screen. Further research is therefore needed to develop better interaction, for example, by use of natural hand gestures.

Gamification added to the two guides did not provide a significantly different experience, but engaged participants in the exhibit. Several participants were very excited to try it out and it showed to be a good way of involving them into the exhibits. Rating on the overall satisfaction with the guide did not show any significant differences, and participants would use both guides if they were available in the museum.

6 CONCLUSION

This work investigated use of smartphones and smart glasses as a platform for delivering narrative content for an augmented reality museum guide. Results showed that smart glasses can better engage visitors into the artwork compared to the smartphone. On the other hand, the smartphone is easier and more intuitive to use while interacting with the artwork compared to the smart glasses. Based on the interview conducted with an exhibition coordinator, the smartphone from a practical point of view seems to be more suitable as a platform for a self-service guide due to its intuitiveness, availability, and its interaction mechanism. Nonetheless, findings from the study have also shown potential for the smart glasses. Several participants who tried them out liked the fact that they did not have to hold them up or experience the exhibition through a secondary screen as was mentioned for the smartphone. However, the smart glasses need more technological advances to make them more comfortable to use in the museum. These advances include expanding the field of view, making the user interface less straining for the eyes to look at, and making the smart glasses more comfortable to wear.

Future studies should investigate which designs and interactions would work well on the smartphone and which would fit the see-through screen of the smart glasses. This study has focused on artworks that were two-dimensional such as collages and paintings. However, further studies should also consider three-dimensional artworks like sculptures and physical architectural models, and research how to deliver narrative content for such objects. Furthermore, future work should also investigate new ways of introducing gamification using such augmented reality guides and how to target different visitor groups, since it was observed that gamification can be an effective way of involving visitors into the artwork. Lastly, the study has shown that both smartphones and smart glasses have their strengths and weaknesses, which when developed appropriately will potentially enhance the museum experience of visitors.

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