# Illuminating shadows: introducing shadow interaction in spatial augmented reality

Gomez-Maureira, M.; Teunisse, C.; Schaffenberger, H.K.; Verbeek, F.J.; Leeuwen, J.P. van; Stappers, P.J.; ... ; Thissen, M.J.M.R.

chi sparks 2014

# Illuminating Shadows: Introducing Shadow Interaction in Spatial Augmented Reality

**Marcello A. Gómez-Maureira**
LIACS, Leiden University
Niels Bohrweg 1, Leiden, NL
ma.gomezmaureira@gmail.com

**Carolien Teunisse**
LIACS, Leiden University
Niels Bohrweg 1, Leiden, NL
lucidlien@gmail.com

**Hanna Schraffenberger**
LIACS, Leiden University
Niels Bohrweg 1, Leiden, NL
h.k.schraffenberger@liacs.leidenuniv.nl

**Fons Verbeek**
LIACS, Leiden University
Niels Bohrweg 1, Leiden, NL
f.j.verbeek@liacs.leidenuniv.nl

## ABSTRACT

In this paper we present a new mode of interaction in 'Spatial Augmented Reality' (SAR) setups, using shadows as interaction input as well as display area. We claim that the combination of shadow interaction and SAR offers a novel, enjoyable and interesting way of interacting with information in a physical manner. This is especially relevant for contexts such as museum exhibits, where digital information and physical objects relate to one another. The results of our usability experiment with a zebrafish model show that users enjoy the combination of shadow interaction and SAR, as well as see a use for it in exhibition environments.

### Author Keywords

Spatial AR, Shadow interface, Public display, Shadow interaction, Spatial interaction, Multi-user awareness, Exhibition display, Emotional display, Playful interaction.

### ACM Classification Keywords

H.5.1 Information Interfaces and Presentation: Multimedia Information Systems – Artificial, augmented, and virtual realities;

H.5.2 Information Interfaces and Presentation: User Interfaces – Input devices and strategies.

## INTRODUCTION

In the last few years, the use of spatial augmented reality (SAR) [2] – often called 'projection mapping' – has emerged as a popular display method for a variety of uses. Examples range from uses in modern art installations, to live visual performances (commonly referred to as 'VJ-ing'), and augmented prototyping [17]. In spatial AR displays, video projectors are used to display virtual content on physical objects in such a way that the content can be interpreted as part of the physical world. It can be argued that this type of display is most effective when the line between the physical and virtual is blurred. As such, any visual artifact in the projection that separates the virtual from the physical would be detrimental to visual illusion that is created. An example of such artifacts is the shadows that occur if the projection path is occluded.

In our study we explore the idea that instead of being problematic, shadows could be used as interaction method and as a way to define an independent secondary display area in spatial AR setups. We propose a system that allows users to interact with an exhibit by casting shadows on the physical model and thereby changing the displayed content in the shadow areas. We call such a mode of operation 'Shadow Spatial AR Interaction' (SSARI). The occurrence of shadows is a concept that is strongly linked to the physical environment. By using shadows as integral part of an interface we argue that the interaction method can contribute to the spatial AR metaphor; the convergence of the virtual and the physical world. We further argue that the use of SSARI promotes spatial exploration of displayed content in a playful way, thereby involving gameful interaction design methodologies (often referred to as 'gamification') [3].

Given that SSARI combines a physical model with virtual content, we expect that it is particularly suited for museums and exhibition environments that use both physical models and digital information in their exhibits. Our primary research question is therefore: *Is the use of 'Shadow Spatial AR Interaction' (SSARI) a suitable method to present interactive content in museums?*

To elaborate on this concept, and to study the feasibility of SSARI setups in general, we developed a prototype of an over-life sized zebrafish model as projection canvas (cf. fig. 1). The prototype was then evaluated in a user assessment experiment and compared to an alternative interactive setup: a touch-based tablet display (Apple iPad, 2010). This comparison was deemed relevant to investigate as previous studies [7, 14, 18] have described the potential benefits of touch-based interaction systems for presenting museum content.



Published in: van Leeuwen, JP, Stappers, PJ, Lamers, MH, Thissen, MJMR (Eds.) *Creating the Difference: Proceedings of the Chi Sparks 2014 Conference*, April 3, 2014, The Hague, The Netherlands.

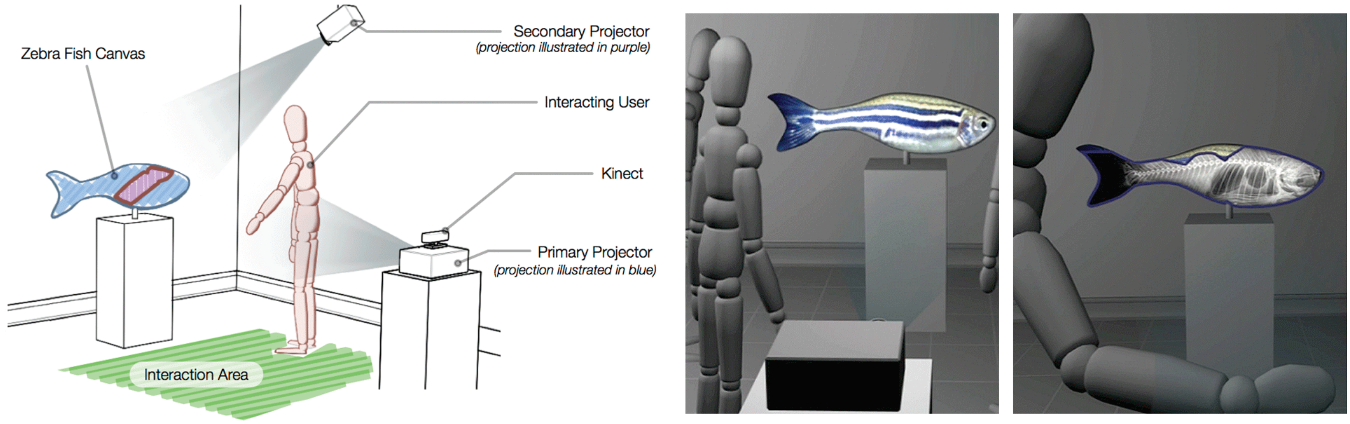


**Figure 1: (Left) Schematic illustration of the SSARI setup, (Middle) Primary projection displaying zebrafish skin, (Right) Secondary projection showing X-ray visualization inside shadow area.**

Since the nature of interaction is different between the two setups, we compare general use parameters such as ease of use, user enjoyment, suitability in museums, and how informatively the content is presented. Our secondary research question is then: *How does the use of SSARI (in the context of museum displays) compare to the use of touch-based displays?*

With respect to our research questions, we hypothesize that: Users will find the SSARI setup suitable for use in museums (H1). Users will find the SSARI setup easier to use than the tablet (H2). Users will report more enjoyment when using the SSARI setup than when using the tablet (H3). Users will find the SSARI setup more informative in regards to the presentation of content than the tablet (H4). Users will find the SSARI setup more suitable for use in museums than the tablet (H5).

In the following sections of the paper we will discuss important prior works that either involve shadows as interface elements or spatial AR setups. We will then describe the conceptual design of a SSARI setup and the functional design of our zebrafish display that uses it. Subsequently, we describe the setup, execution, and results of our usability assessment efforts before drawing conclusions. Finally, we will discuss the outcome of our study before ending with considerations regarding future work.

## BACKGROUND AND RELATED WORK

The combination of SAR with shadow interaction has so far remained unexplored. Previous work has, however, investigated these concepts individually and shown various ways in which they can be used as effective components in user interfaces.

SAR displays are often used to provide unique visual aesthetics that could not be achieved with traditional screens. One research [12] uses two projectors to augment a physical model of the Taj Mahal. By modifying the projection content, the model's physical appearance can be modified in an instant despite the static nature of the model itself. Another study used SAR for medical training purposes: In 'BodyExplorerAR' [13] a full-body mannequin serves as canvas for projection content. Users of the interface can explore the anatomy and physiology of a human, and receive direct feedback to see the consequences of actions they perform on the mannequin.

What these studies have in common is the use of SAR for the purpose of real-time interactions with physical objects. These studies illustrate how useful SAR can be in educational contexts by allowing the easy and dynamic linking of digital information to physical structures. In each of these studies, the occurrence of shadows would introduce an unwanted artifact into the interaction and possibly distract the user's immersion. However, studies that explore shadows as interaction method show that shadows can also be used effectively as part of the interface.

Such an implementation can be seen in a study about crowd audience participation [8] in which a modified version of the game 'Missile Command' is projected onto an elevated screen. The audience can interact with the game by occluding the projection path by hitting a beach ball into the air. Another study introduces the term 'Shadow Reaching', an interaction technology using the properties of perspective in shadow projection to let a single user extend his or her reach on a large screen [15].

Within the context of user interaction, shadows are widely regarded as familiar and intuitive to users, and are therefore considered to be well suited to act as interface element in interactive visual applications [4, 8, 15]. The general understanding of how shadows work offers perceptual advantages for applications that link physical actions to virtual responses and vice versa [9, 20, 15]. Studies [1, 20] have also emphasized favorable economic aspects of using shadows as form of interaction. In addition to such practical considerations, user experiments [1, 9, 6] showed that the involvement of shadows can introduce emotional aspects to an interface due to its expressiveness, inducing a sense of human presence in a virtual environment.

The interaction prototype described in this paper aims to capture and combine the separate benefits of SAR and shadow interaction, specifically visual aesthetics, immediacy, and emotional impact. We believe that the resulting combination would be well suited for interactive exhibitions. Research into interactive museum installations suggests that content should be presented in a way that lets users engage and experience it [5]. This approach is often chosen when creating exhibitions for children, but rarely implemented for older target groups. In our study we aim to develop an interaction prototype that offers adult audiences a way to engage with multiple information layers without compromising the playful experience. We argue that our approach will not alienate children, but rather will offer an interaction interesting and sophisticated enough for adults to enjoy.

## IMPLEMENTATION

In order to explore the potential of SSARI through user evaluation, we built an over-life size version of a zebrafish to serve as projection canvas (cf. fig. 2). This zebrafish prototype allows users to explore different layers of content (among other the outer skin, an X-ray visualization and a basic anatomical schematic) by creating shadows and by moving closer to and further away from the fish. While the interaction system could have been built around the exhibition of any 3-dimensional object, we chose to portray the zebrafish due to its relatively simple shape and ongoing research using zebrafish data at our faculty [11, 10].

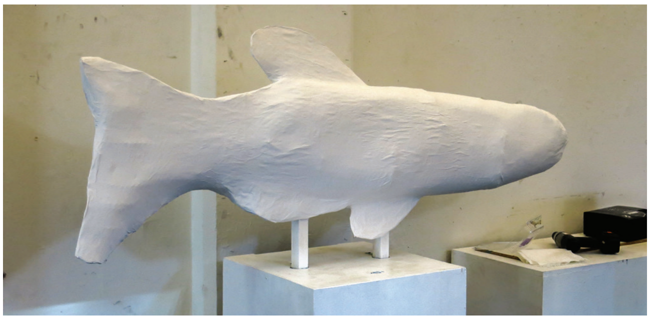

**Figure 2: Prototype zebrafish model.**

Based on a previous SAR study involving two projectors [12], we set up two projectors for the display of content. The first projector, referred to as primary projector, was positioned in front of the zebrafish model and was used to project a looping video of the zebrafish skin on the model (cf. fig. 3).

A Kinect motion controller (Microsoft, 2010) was positioned directly on top of the primary projector and used to capture the shadow and the distance of interacting users[1]. The secondary projector was placed on an elevated position and was used to project content on the shadow areas created by the users. In the default state of the prototype, only the primary projector displays content. Once users enter the projection path between the primary projector and the zebrafish model, a shadow is created on the physical canvas. This shadow is then 'filled in' with supplementary content by the secondary projector (cf. fig. 4).

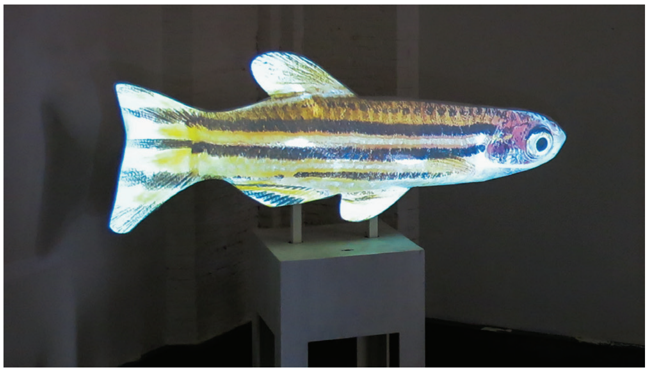

**Figure 3: Prototype zebrafish model with skin projection.**

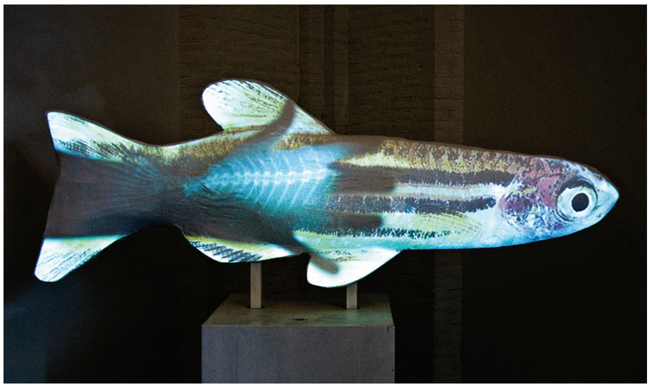

**Figure 4: Prototype zebrafish model with supplementary X-ray projection on the shadow area, formed by a hand.**

The projection of such content is slightly delayed due to the latency of the Kinect device. As such, fast movements can temporarily cause a visible offset between the position of shadows and the position of the projected supplementary content. It should be noted however that users have not mentioned this delay during our usability assessments (cf. section 'Usability Assessment').

The video content was graphically deformed in such a way to accommodate the physical canvas shape and to correct slight distortions in the setup. The video further included small light distortions (caustics) to simulate the effect of the fish being under water. The effect was added in order to draw attention to the display. It also provided a subtle visual atmosphere of the natural environment of the exhibition subject.

At the beginning of our study, we envisioned to use a single layer of supplementary information that users would be able to reveal through creating a shadow on the canvas. However, in response to a first user assessment (cf. section 'Usability Assessment'), we decided to include multiple layers (cf. fig. 5) for the secondary projection. Users would then be able to explore four supplementary layers: 1) a basic anatomic schematic, 2) a transparent albino specimen, 3) an X-ray visualization, and 4) a histological view.

[1] From a technical perspective it was not the visible shadow that was captured but rather the depth information (e.g. the user's body) captured through the infrared capabilities of the Kinect. By positioning the primary projector as closely to the Kinect as possible, we were able to align the visible shadow to the captured depth information. A small remaining offset between the two devices was corrected on a software level.

**Figure 5: Visualization layers used in the prototype (from top to bottom): outer skin, basic anatomic schematic, transparent albino specimen, X-ray visualization, histological view.**

From early user assessments with a simplified prototype (cf. section 'Early Prototype Assessment') we learned that users might need to be actively invited into the interaction area of the primary projector. As a solution we installed a simplified 'zebra crossing' (cf. fig. 6) leading from the primary projector to the fish canvas. Each stripe was placed on the floor and labeled in such a way as to indicate to the user what secondary visualization layer would be revealed if they were to create a shadow when standing at that particular distance. Additionally, we created a stick-figure pictograph sign that was mounted directly under the fish canvas, informing users that interaction would be triggered by stepping into the projection path of the primary projector.

To switch between individual layers, users could move closer or further away from the model. The transition from one layer to another was implemented through a fade over.

On the software side of our prototype, we created a program in 'vvvv' (a node-based visual programming environment) that interprets the measurements of the Kinect depth sensor to control the output of the secondary projector. The program has to be calibrated whenever the positioning of the physical model, the Kinect or the projectors changes in order to correctly project onto the user's shadow. To calibrate the Kinect we used existing code written in 'vvvv' [19] that calculates the required distortion of display content by going through a series of user guided calibration steps. In order to accurately distort the projection content, the program also needs a virtual 3D model of the physical model, which was created by scanning the physical model through handheld operation of the Kinect. We consequently aligned the virtual 3D model with the physical model by adjusting the projection settings. As a result any texture that is applied to the virtual model in our program corresponds to the physical model.

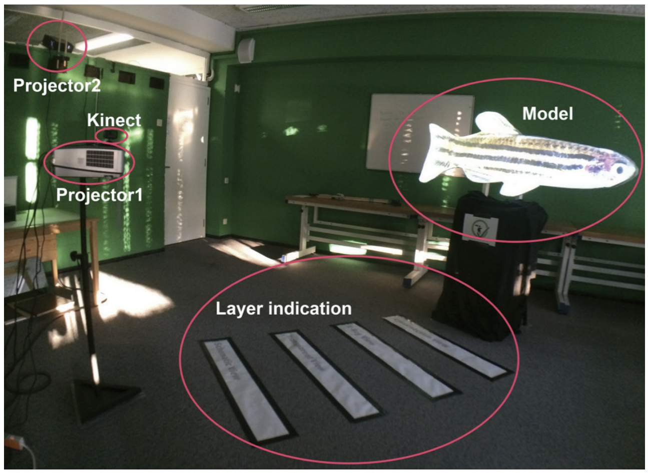


**Figure 6: Prototype setup for second user assessment.**

To implement the transition of different visualization layers we created an image sequence of the visualizations that served as texture for the virtual 3D model.

The depth values recorded by the Kinect in the case of user interaction are used to select the image frame that corresponds to the measured specific physical depth. Furthermore, we use the depth image of the Kinect to create a matte that blocks out the projection of any content not covered by the shadow of a user. A schematic of the interaction processes with our software can be seen in figure 7. The core usability requirement that our prototype had to fulfill was that its functionality would have to be self explanatory through exploration by users. This meant that once a user had understood that the primary projection path could be interrupted to show supplementary information, all other functionality would be revealed by users through experimenting with the interface.

Finally, we would like to point out that SSARI can generally also be implemented by using only a single projector. In such a case the projector would have to be set up in such a way that interacting users cannot interfere with the projection path. While the projection of the user's shadow would only be simulated, implementing SSARI in this way would reduce the financial requirements. On the other hand, using two projectors allows users to easily understand from where shadows are projected and therefore where they can interact with the display.

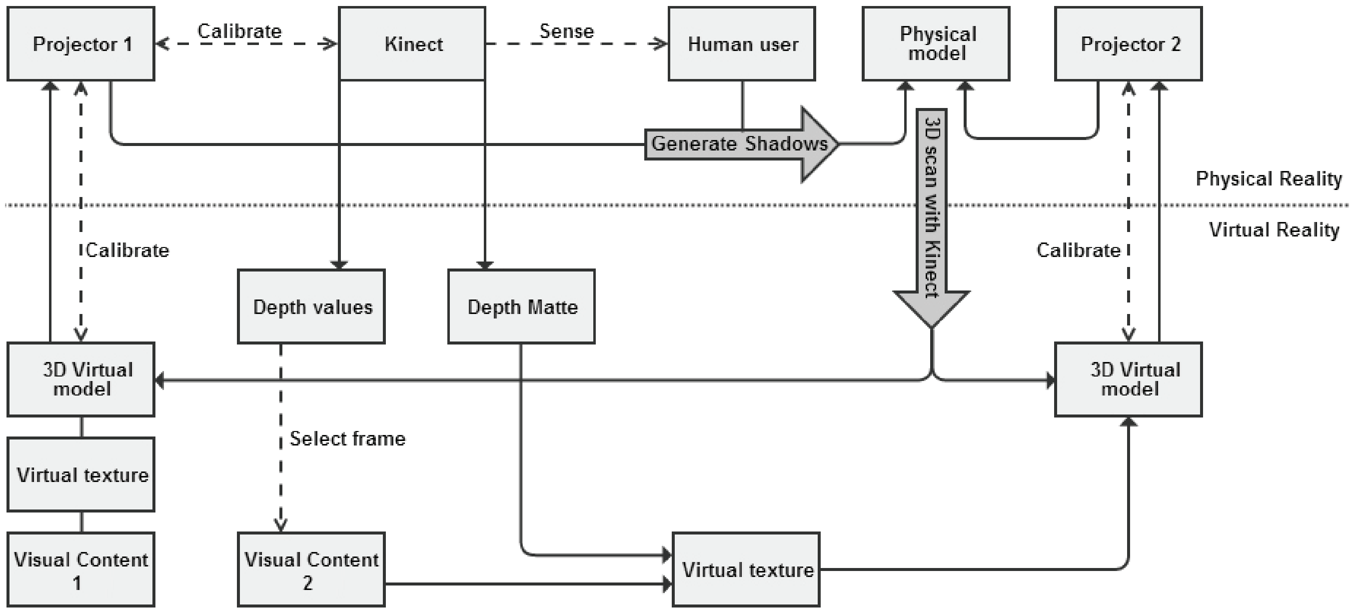


**Figure 7: Schematic showing the interaction processes with our prototype software.**

### Implementation Issues

In the development of our prototype we had to accept some limitations due to constraints in time and resources. One such limitation is the fact that users were still able to interrupt also the secondary projection path if they got too close to the physical model. In such a case, both the primary and the secondary projections would be occluded without means to fill in the shadow area, resulting in a visible (black) shadow. Consequently, our implementation of SSARI does not allow users to touch the model. We discuss possible solutions to this issue later in this paper (cf. section 'Future Work').

Another limitation can be seen in the fact that while multiple users could interact with the prototype at once, the determination of which layer to visualize was dependent on whichever user was closest to the model. As such the layer indications positioned on the ground (in form of a zebra crossing) only corresponded to the position of the user closest to the model.

One constraint that applies when multiple users interact with the system is that our current implementation does not yet display multiple shadow layers at the same time. Consequently, only one user is in control over which content is displayed in all shadow areas.

On a technical level it should be noted that the depth sensing capabilities of the Kinect are low in resolution, resulting in pixelated edges around the detected shadows. Furthermore, fast movements caused a delay between the visual shadow and the supplementary projection.

## USABILITY ASSESSMENT

To assess the usability of SSARI we devised two user experiments at different stages of the research. An early prototype was built for the first experiment to explore potential functionality and use cases of SSARI. The second user experiment involved the zebrafish model described previously in the 'Implementation' section.

### Early Prototype Assessment

In our first usability experiment we developed a simplified version of the SSARI system. Two projectors were used to project content onto an inoperative computer screen that had been painted white. The primary projector was positioned in front of the computer screen and displayed a looping video of an operating system in use. A secondary projector was positioned at an angle of 60 degrees to display the image of an electronic circuit board. As described previously, a Kinect was used to capture any shadows created by users. This information was then interpreted by our program to display the circuit board imagery on the shadow areas (cf. fig. 8). This early prototype did not change content based on the depth of the shadow. Users could therefore explore two layers at this point: the primary projection and a single shadow-area projection.

We then invited a group of five Master students with backgrounds in interface design to participate in a focus group as expert users. The focus group participants were asked to explore the prototype as a group. During this time we observed the participants and took notes. After approximately 5-10 minutes, the group had decided it had seen enough to start a discussion about possible use cases. Other topics of the discussion were: positive and negative aspects of the interaction, how to invite users to disrupt the primary projection path, and words that described the interaction system. Finally, we asked participants to openly rate the prototype in terms of usability and innovation.

In general the prototype received positive responses in the context of use as exhibition system. Some participants criticized the limited use of interaction possibilities of the early prototype. We were furthermore advised to make sure that future users understand that the projection path can, and in fact should be, interrupted in order to facilitate interaction. During the focus group session, participants seemed to focus on exhibition uses of the interaction system, noting its ability to attract attention and its novel way of interaction. This was also attributed to the fact that the interface did not allow much varied functionality to perform complex tasks. Participants quickly came up with ideas that involved interaction in depth, noting that this dimension could be used to travel back and forth in time or to zoom on a detail. The prototype was rated by each participant, resulting in an average usability rating of 6.8 and an average innovativeness rating of 6.6 (with 1 being worst and 10 being best).

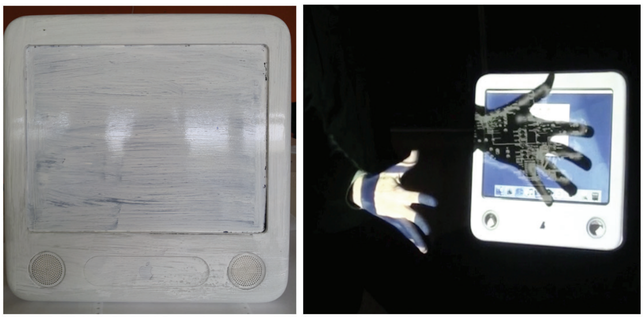

**Figure 8: (Left) Painted computer screen used as canvas in the first user assessment, (Right) First user assessment shown in action.**

It should be noted that while we were interested in how participants would score the prototype, our primary goal was to spark a conversation between participants that would uncover problematic or ill-defined aspects of the prototype and the SSARI system in general. In many cases, we had already considered specific design solutions mentioned by the participants for implementation in the subsequent prototype. By observing the group discussion we were however able to make an early evaluation regarding what kind of interactivity might be expected from users. Most importantly, it provided an early indication for the suitability of SSARI as form of interaction with exhibition content. As such the focus group session should only be partially understood as usability assessment and also as an early evaluation of the interaction concept itself.

### Zebra Fish Display Assessment

To evaluate the usability and user enjoyment of our interactive zebrafish setup, we chose to conduct a comparative experiment. We created a small website for the experiment that contained links to each individual zebrafish visualization. During the experiment, the tablet device was used to connect to the website to simulate a simple touch-based information display. The image resolution of the visualizations was chosen at twice the size at which the image would be displayed on the website. This allowed users to enlarge the view of a visualization using a 'zoom-out' finger gesture while retaining a consistent image quality. When zoomed into an image, participants were able to use finger gestures to pan the image or zoom out again.

To ensure that the comparison between the two systems is as fair as possible, we tried to provide equality in the quality and quantity of interactions available. In addition to the visualizations shown on the SSARI setup, the website therefore also featured a high-resolution image viewer for displaying the histological view. The viewer has been created by the Pennsylvania State University [16] and was linked to in such a way that participants would assume it to be part of the experiment website. This additional visualization was added only to the tablet set up to make up for functionality it did not offer.

The experiment took place with 16 participants between 21 and 38 years of age that had been invited from the faculty premises. To test how the interaction setups would be assessed in a multi-user setting, we asked participants that knew each other to perform the experiment at the same time. A total of 12 participants took the experiment in pairs of two while the remaining 4 took the experiment alone.

Participants were told to take as much time as they wanted to explore the display content after which they would be asked to explore the same content on a different interface. In doing so, participants experienced both setups and could then be asked to compare them. The order in which participants used the two setups was switched after each of the consecutive test sessions. Once participants had interacted with both setups they were asked to fill in a semi-structured questionnaire. Questions included familiarity with touch devices, frequency of museum visits, interestingness of the presented content, ease of use for each of the displays, enjoyment when using each of the displays, and questions regarding the suitability of the setups for use in museums.

## RESULTS

The two setups scored roughly the same on average regarding their ease of use, resulting in ratings of 5.9 (touch display) and 5.8 (projection display) out of 7. When asked for their preference between the two for ease of use, exactly half (50%) of the respondents chose the touch display and half chose the projection display.

In terms of self-reported enjoyment, the touch display scored a 4 out of 7 on average, while the projection display a 6.4 out of 7. Asked to choose which of the two displays was more fun the majority of the respondents (93.8%) preferred the projection display. When inquiring about the suitability in museums, the touch display scored 4.2 out 7 on average. Here the projection display scored an average of 6.4 out of 7 with no rating being lower than a 5. In terms of how informative the two displays were perceived relative to each other, 7 respondents (44%) found the projection display more informative, while 9 respondents found the touch screen more so.

When asked via an open question for any further comments or opinions they might have, respondents indicated that they would like additional information to accompany the content either through text or voice narration. The ability of the projection display to accommodate multiuser interaction on its own was described as an advantage over touchscreen displays by two of the respondents. On the other hand, quality and detail of information displayed by the projected display was criticized as poorer relative to the touch screen display. Regarding our usability requirements, all participants discovered the four supplementary information layers without being prompted to explore them.

## CONCLUSIONS AND DISCUSSION

The results of our user assessment experiment suggest that the majority of users found the SSARI system suitable for use in museums, and significantly ($p = 0.0001$) more suited than the use of the touch display (H1 and H5 confirmed). In terms of ease of use, users found our prototype somewhat easy to use, rating it with an average of 5.8 out of 7. The touch display was rated an average of 5.9 and therefore slightly easier to use. While the difference is not significant ($p = 0.42$), our second hypothesis cannot be confirmed (H2 rejected). In regards to enjoyment of the interaction, users reported consistently high enjoyment (6.4 out of 7) of our SSARI implementation, with 15 out of 16 participants finding it more enjoyable than the touch display (H3 confirmed). Lastly, the majority of users (9 out of 16) stated that the touch display was more informative (H4 rejected).

Overall we conclude that the concept of SSARI is practically feasible, and (from a user perspective) suited to be used in museum environments. Participants in our research were enthusiastic about exploring the display content through SSARI. Our experiments show that the strengths or SSARI are found in how content is displayed and interacted with. Given the fact that the tablet system was found to be more informative yet less suited for museum use, we conclude that users may prefer traditional forms of displays when trying to access more in-depth information. As such we see the ideal use of SSARI in a complementary setting where detailed information is made available through other means (e.g. textual or auditive).

A SSARI setup that includes depth-sensing of interacting users is particularly suitable for exploring different layers of content that correspond to the same physical shape. Another strength of SSARI is that it allows several users to interact with the display at the same time and hence also allows for interaction and exchange among different users. In our prototype, users shared their shadows in such a way that the same depth visualization layer was shown for each of them. However, the system could also be set up so to give each user full depth control, and therefore selection of layered display content, of his or her own shadows.

As we pointed out earlier, SSARI can technically be implemented with a single projection. However, we argue that doing so also reduces the immediacy and playfulness of the setup. In the end, we do not consider SSARI a technique that excels in productivity but rather in user enjoyment. Efforts regarding a simpler implementation should therefore be mindful to not lose the appeal that it provides to its users.

Finally, in addition to being used in museum environments, we see interesting potential for SSARI in artistic performances and installations, as well as the implementation in experimental games and educational setups. It could, for example, be used to learn about human anatomy at schools. We hope that our research can inspire the creation of more examples involving SSARI.

## FUTURE WORK

In the future we will further experiment with different forms of interactions and visualizations in our zebrafish prototype. One possibility we are currently exploring is the visualization of histological views in such a way that users can interactively 'slice' through the zebrafish by moving closer or further away. This functionality has been added to the prototype setup but has not yet been evaluated with user experiments.

As mentioned in the previous section, a future step in terms of interaction would be to implement the possibility to display multiple shadow layers at the same time. This way, each user would always be in control over which content to display regardless of the interactions of other users. Furthermore, we are interested in adding a secondary, traditional display to the prototype for complementary use. Interacting with the fish model could for example trigger the display of more in-depth information on a secondary screen (cf. fig. 9).

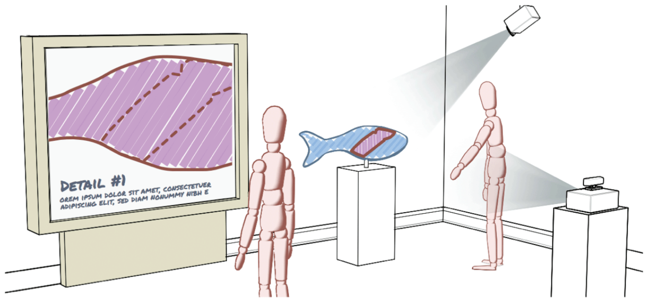


**Figure 9: Schematic showing the zebrafish prototype complemented by a secondary screen, showing a zoomed-in version of the secondary display layer.**

With respect to the implementation, we want to create a more solid installation. From a technical standpoint, we would like to perfect the match between the physical model and the virtual projection. This could for example be achieved by 3D printing the physical model based on the particular virtual model that will be projected onto it. We also consider recreating the prototype in such a way that the second projection would occur from within or behind the model (given the use of semi-transparent building materials). Modifying the prototype in such a way would allow users to come very close to the model and even touch it; enabling even more possibilities for interaction.

In regards to our research, we recognize that our installation may have scored high on enjoyment due to the novelty of the interaction as well as the novelty in the presentation of content. While both aspects have been implemented in other projects before, it is unlikely that many users would consider them common. Future research should therefore evaluate whether the use of SSARI systems provide consistently high user enjoyment, and if so, what the underlying reasons may be. In the end it may very well be that the success of SSARI depends on its ability to surprise users.

Another aspect to consider is the fact that this study has focused on technical feasibility of SSARI on the one side and its user reception on the other. The suitability of a technology however also depends on the involvement of other stakeholders. When considering the use of SSARI in museum environments, future research of SSARI should investigate aspects such as technical maintenance and upgradeability.

We hope that this research inspires museums and artists alike to use SSARI as well as participate in its ongoing research.


## ACKNOWLEDGEMENTS

We would like to thank all the participants that took part in our user experiments. Furthermore we want to specifically acknowledge Meggy Pepelanova, Georgios Lampropoulos, Livia Teernstra, Isabelle Kniestedt, and Bram Snijders for their support in this research.


## REFERENCES


1. Apperley, M., McLeod, L., Masoodian, M., Paine, L., Phillips, M., Rogers, B., and Thomson, K. Use of Video Shadow for Small Group Interaction Awareness on a Large Interactive Display Surface. 81–90.
2. Bimber, O., and Raskar, R. *Spatial augmented reality*. Merging real and virtual worlds. A K Peters Limited, 2005.
3. Deterding, S., Dixon, D., Khaled, R., and Nacke, L. From Game Design Elements to Gamefulness: Defining Gamification. 9–15.
4. Herndon, K. P., Zeleznik, R. C., Robbins, D. C., Conner, D. B., Snibbe, S. S., and Van Dam, A. Interactive Shadows. 1–6.
5. Hornecker, E., and Stifter, M. Learning From Interactive Museum Installations About Interaction Design for Public Settings. 135–142.
6. Jacquemin, C., Gagner´e, G., and Lahoz, B. Shedding Light on Shadow: Real-Time Interactive Artworks Based on Cast Shadows or Silhouettes. 173–182.
7. Kidd, J., Ntalla, I., and Lyons, W. Multi-Touch Interfaces in Museum Spaces: Reporting Preliminary Findings on the Nature of Interaction. *Rethinking Technology in Museums: Emerging Experiences. University of Limerick* (2011).
8. Maynes-Aminzade, D., Pausch, R., and Seitz, S. Techniques for Interactive Audience Participation. In *ICMI '02: Proceedings of the 4th IEEE International Conference on Multimodal Interfaces*, IEEE Computer Society (Oct. 2002).
9. Miwa, Y., and Ishibiki, C. Shadow Communication: System for Embodied Interaction with Remote Partners. 467–476.
10. Potikanond, D., and Verbeek, F. Visualization and analysis of 3D gene expression patterns in zebrafish using web services. In *IS&T/SPIE Electronic Imaging*, International Society for Optics and Photonics (2012), 829412–829412.
11. Potikanond, D., Verbeek, F., et al. 3D visual integration of spatio-temporal gene expression patterns on digital atlas of zebrafish embryo using web service. *ACEEE International Journal on Information Technology 1*, 3 (2011).
12. Raskar, R., Welch, G., Low, K.-L., and Bandyopadhyay, D. Shader Lamps: Animating Real Objects with Image-Based Illumination. 89–102.
13. Samosky, J. T., Nelson, D. A., Wang, B., Bregman, R., Hosmer, A., Mikulis, B., and Weaver, R. BodyExplorerAR: Enhancing a Mannequin Medical Simulator with Sensing and Projective Augmented Reality for Exploring Dynamic Anatomy and Physiology. 263–270.
14. Shneiderman, B. Touch Screens Now Offer Compelling Uses. *Software, IEEE 8*, 2 (1991), 93–94.
15. Shoemaker, G., Tang, A., and Booth, K. S. Shadow Reaching: a New Perspective on Interaction for Large Displays. In *UIST '07: Proceedings of the 20th annual ACM symposium on User interface software and technology*, ACM Request Permissions (Oct. 2007).
16. The Pennsylvania State University. Zebrafish Atlas VirtualSlide Viewer, 2013.
17. Verlinden, J. C., De Smit, A., Peeters, A. W., and van Gelderen, M. H. Development of a flexible augmented prototyping system. In *WSCG* (2003).
18. vom Lehn, D., and Heath, C. Accounting for New Technology in Museum Exhibitions. *International Journal of Arts Management* (2005), 11–21.
19. Woods, E., and McDonald, K. Notes from Art&&Code: Calibrating Projectors and Cameras: Practical Tools, 2011.
20. Xu, H., Iwai, D., Hiura, S., and Sato, K. User Interface by Virtual Shadow Projection. 4814–4817.