Building Realistic Physical Proxies in Mixed Reality - Literature Review

SIMON ALERS, University of Lübeck

CCS Concepts: • **Computer systems organization** → **Embedded systems**; *Redundancy*; Robotics; • **Networks** → Network reliability.

ACM Reference Format:
Simon Alers. 2023. Building Realistic Physical Proxies in Mixed Reality - Literature Review. 1, 1 (January 2023), 6 pages. https://doi.org/10.1145/nnnnnnn.nnnnnnn

1 INTRODUCTION

Mixed Reality is a technology, that is growing more important in many fields. Combining Real World Objects and Virtual Reality is often a difficult task. Therefore, this literature review looks at past works related to this problem. It focuses on physical proxies used in mixed reality in order to enhance design and protoyping processes and considers the quality of the solutions.
The search terms for this paper were "physical proxies in mixed reality" and "mixed prototypes".

"Mixed prototypes for the evaluation of usability and user experience: simulating an interactive electronic device" created by four university students from brasil. According to their paper, literature on the topic of mixed prototypes is rare. We will see if this literature review comes to the same conclusion and whether there has been a change in frequency of papers released on the topic per year, since the paper by Faust et al. was published in June 2019

In their paper they built a physical proxy out of Polyurethane, which resembled the shape of an epson projector. (See Figure 1) Physical buttons where also created for the physical prototype, so that it can be interacted with. The visuals of the projector where realised by a mobile augmented reality solution. As visible in Fig 1 the AR compatible tablet was placed above the physical proxy (A) and displayed the virtual image of the Projector to the user (B). In my personal estimate the method they used provides a very low level of immersion, compared to an AR head mounted display. The users have to look at the mobile devices screen in order to interact with the object. This is not as natural as looking at the object itself. I expect the users to feel a disconnect between what they have in their hand and what they see on the Screen. This may cause a low level of immersion
The biggest problem was a bad implementation of AR, which caused problems when interacting with the prototype. Overall the prototype was still evaluated as a useful tool for Mixed Prototyping. The reason for this was that similar to the real Projector, difficult tasks showed a longer time to complete in comparison to easier tasks. In conclusion the mixed prototype could be used for comparative purposes.

2 EARLY WORKS SHOWING FIRST STEPS TOWARDS MIXED PROTOTYPES

Imre Horvath is a professor at the Delft University of Technology and has published numerous papers focusing on "cyber-physical systems" and design/system thinking. Together with Jouke Casper Verlinden of the University of Antwerp wrote the paper "Enabling Interactive Augmented Prototyping by a Portable Hardware and a Plug-In-Based Software Architecture" [8] on physical prototypes in 2008.
This Prototype, which they named "I/O Pad", used a projector based Spatial Reality solution. (See Figure 2) Projectors where used to project a virtual image onto the surface of white physical models. There were two versions of the prototype. One larger more powerful version and one smaller, more mobile version.
They used a Wii Remote connected via Bluetooth to a small Computer with a touchpad and a projector. An Infrared Motion Capturing System was able to pin point the exact 3-Dimensional location of the point, the Wii Remote was pointed at on the surface. The Interaction consisted of

Author's address: Simon Alers, alerssimon@gmail.com, University of Lübeck.

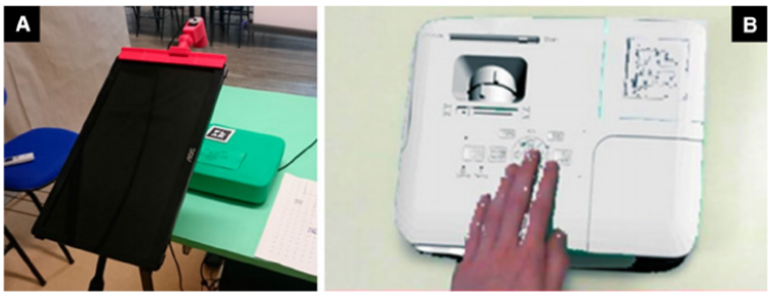

Fig. 1. Augmented reality for the multimedia projector Epson × 14: setup (a) and displayed image (b) [2].

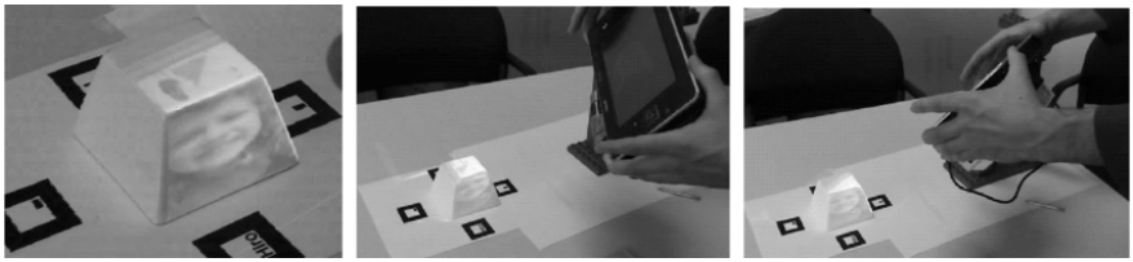

Fig. 2. Handheld I/O Pad in use. [8].

pointing the Wii remote and additionally interacting with the touchpad on the I/O Pad.

The software Architecture they used to build the prototype and iterate the physical model was called WARP 2.0. This software used common 3D modeling and simulation practices and was therefore compatible with existing design practices.

The biggest problem with this prototype was the large threshold necessary to overcome, for implementing this technology. The hardware solution wasn't widely available. My evaluation is, that today, there are Head Mounted Displays for VR and AR, which provide a much better technological interface for interacting with physical proxies. The Experiments of this paper are great to see the beginnings of what Physical Proxies looked like, but arent relevant in the current time. Also the paper by Faust et al.[2] brings up another disadvantage of the spatial reality solution: When someone uses their arm, to interact with the prototype, a large section of the projection surface is covered by the shadow of the users hand and arm.

There is another research paper from Korea, which evaluates appearanche design of products using Spatial Augmented Reality and physical proxies.[6] It has the name "Spatial augmented reality for product appearance design evaluation". It uses a projector, which beams a virtual representation of a product onto a white mockup of the product.(See Figure 3) It is mainly used to prototype different color variations of a product. The appearance of the color can quickly be changed by switching the image projected by the projector.

3 RESEARCH PAPERS USING PHYSICAL PROXIES TO IMPROVE PROTOTYPING

The paper "Tangible AR interaction based on fingertip touch using small-sized nonsquare markers" [5] from 2014 focuses on markers used on physical objects for tracking their respective position in Augmented Realitiy systems.

Fig. 3. Spatial Augmented Reality Setup [6].

Fig. 4. AR environment used. [5].

It is written by Ho-Kyun Jung and Hyungjun Park, a professor at Chosun University in South Korea.
According to this paper there are often times problems with placing markers onto long objects, like a finger. This is due to the fact that most markers are square and are very small when placed onto such thin objects. Thus they created non square markers, that can be attached to a finger seen in Figure 4 on the right. As you can see in this figure, they are using the same method for using mixed prototypes in augmented reality as the paper by Faust et al [2]. The setup consists of a mobile AR Devise showing the mixed Prototype held behind the mobile device.
The paper targets to increase immersion, by tracking the finger. This improves fingertip interactions with the prototype, according to the paper, because it increases the immersion.
Today there are modern technologies, like finger tracking, which can fully reproduce the functionality shown in this paper. It is still interesting to see, that they used the same Experiment setup as the paper by Faust et al. The fact that a research group in a country located far away used the same technique, gives an indication, that the Technique is widely used for research purposes.

The paper "Utilizing end User Input in Early Product Development" by Young Mi Choi was published in December 2015.[1]
It focuses heavily on improving the Design Process of Assistive Technologies. Assistive Technologies are devices, that support people with desiabilities or older people.
The paper states that working closely with the target group during the developement process greatly improves the success of the final product. Analysing how users interact with a product and what the expectations of the users towards the products functionalities are, is very important.

Fig. 5. AR Product Developement

First the paper reviews results of a previous paper, where sketches or renderings are used for prototyping. The different prototypes are compared in their ability to accurately prototype the user input of the prototype.
In the later part of the paper, they investigate Augmented Reality methods for analyising User Input with different Prototypes. The experiment setup is once again realized with the help of mobile augmented reality and a physical proxy. This is visible in Figure 5.
The study concludes that all of the design artifacts looked at are a valueable tool for making design decisions during the prototyping developement stage. It allows fast iteration of early prototypes, which can greatly reduce the developement cost and time consumption of a product design process.
The paper "Prototyping strategies for multisensory product experience engineering" provides further analysis of the multisensory experience perceived by users interacting with physical proxies.[3] In their research, they use Virtual Reality and physical prototypes with physical keys and actuating strips, that conform to the shape of the virtual object.
In their research they conclude, that Mixed Prototype provide a valid method for prototyping Products.

4 RECENTS WORKS LOOKING INTO POSSIBLE IMPROVEMENTS FOR MIXED PROTOTYPING

The paper "Making despite Material Constraints with Augmented Reality-Mediated Prototyping" [7] is the most recent one i have presented so far in this literature review. It was published in April of 2020 by Sowmya Somanath Sowmya Somanath of the University of Victoria in Canada. The problem they want to solve is when there isnt enough material during prototyping. Then you can use their solution, to substitute this missing component with an augmented one. The Part (See Figure 6)

In a Literature Review on Mixed Reality in design prototyping conducted by Chris Snider of the University of Bristol in September of 2021 108 papers were analyzed.[4] The benefits of physical prototypes and virtual prototypes

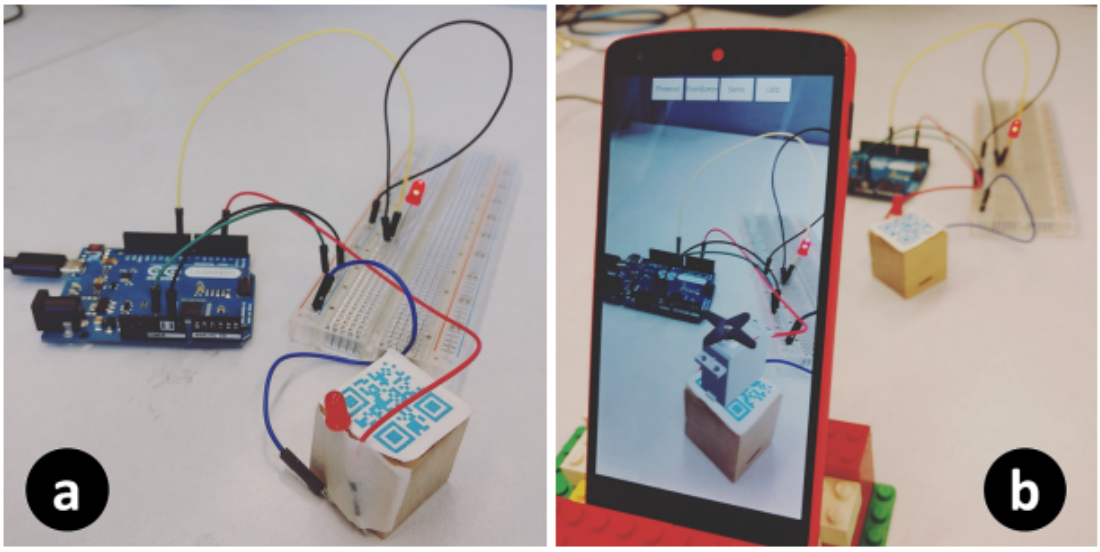

Fig. 6. AR-mediated Prototyping: (a) trackable wooden cube proxy (b) companion AR application. [7]

are presented. In Figure 7 you can see a how each prototype has its own benefits but none of them are great in every way. So this paper also looks at mixed reality, because it can bring both technologies together which can improve the shortcomings of the respective other. In their paper they state, that there have been many papers in the past years showing the value of mixed prototyping in a particular use case. The literature review wants to bring the results together and show a generalized Value analysis of mixed prototyping, instead of focusing on one specific use case.

5 DISCUSSION

In comparison to the interactive Spatial Augmented Reality Model in the paper by Horvath et al. [8] the Spatial Augmented Reality solution for Car Appearances [6] solution doesnt require the user to interact with the mixed prototype itself. Thus the usage of spatial AR is reasonable in my opinion. It doesnt require the user to wear any additional hardware like a head mounted display, so it provides more comfort. In other use cases, where interaction is necessary, a more immersive technology would be necessary in my opinion. Unfortunately a Mixed Prototype utilizing a head mounted display could not be found during my literature research. In general, most papers on the topic were released between 2007 and 2014, hence the technical solutions are expected to be a bit outdated. So the Solution by Faust et. [2] al is the best solution in my opinion.

6 CONCLUSION

Generally, the consensus is, that physical proxies can help greatly during prototyping in the early development stages. The great magnitude of flexibility was often mentioned as the biggest advantage of physical proxies compared to virtual ones. Cost was also a big factor, which made the mixed reality prototype a better solution in comparison to traditional prototypes.

The presented solutions often used older Augmented Reality implementations. Often times the experiment setup was using mobile AR, where the user has to look at the mobile devices screen, in order to see the device and interact with it. This is an unnatural interaction, and is also mentioned, as possible improvements in research papers. The reason, why there is no more research on the topic is

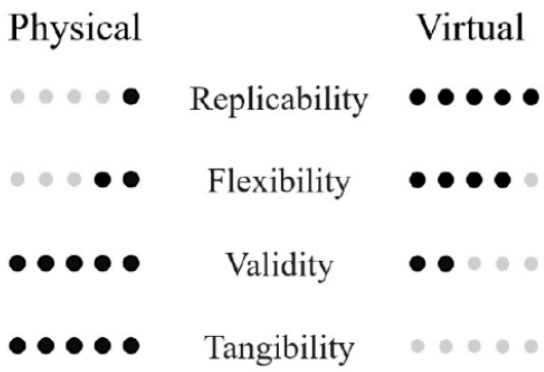

Fig. 7. Spectra of replicability, flexibility, tangibility, and validity, showing how virtual and physical prototypes can be considered counterpoint. [4]

probably the fact, that the scientific consensus seems to be already established, that mixed prototypes are a very useful tool in prototyping. Apparently there is no more research to be done, because the solution is already beginning to become widely available for companies, through the means of the Microsoft Hololens for example. This device enables manipulation of 3Dimensional Objects in a collaborative environment, where each person can see each other with their own eyes. Materials for the Physical prototype were mostly plastic. 3D printed or sculpted models are the most common methods for creating the physical proxy.

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