LightSpace: An Interactive, Projection-Mapped (doll)House

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CHI 2020 Extended Abstracts, April 25–30, 2020, Honolulu, HI, USA.

ACM ISBN 978-1-4503-6819-3/20/04.
DOI: https://doi.org/10.1145/3334480.3383180

Abstract
The home of the future will be an interface (in itself) much like current, omni-present screen-based, interfaces. Designing the interior of your home will be as gratifying and immediate as a click is today, with modular digital furniture becoming the status quo and their design democratized and in the hands of users.

In this paper, we present *LightSpace*, an exploration for the future of design for the home. LightSpace focuses on a very specific solution to a simple problem -- designing and stylizing an entire room with playful delight in mind. With our small-scale proof-of-concept tangible user interface (TUI), we account for the direct physicality of designing within a physical space by allowing users to move mini 3D printed furniture pieces in a projection mapped dollhouse and switch materials using a magical wand (NFC).

This exploration acts as a small-scale vehicle for us to investigate the usefulness, delight, feasibility, and possible ubiquity for such an interface in the future.

Author Keywords
Projection mapping, Tangible interfaces, Interactive, Dynamic interfaces, Spatial augmented reality, NFC, Optical tracking

CSS Concepts
• **Human-centered computing** → *Displays and images*; • **Hardware** → *Tactile and hand-based*

Figure 1: In-house projection mapped armchair

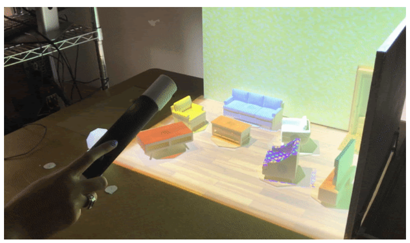

Figure 2: Dollhouse system with NFC wand interaction

Figure 3: Our initial pass for the dollhouse system with a top-mounted camera

interfaces; • **Computer systems organization** → *Sensors and actuators*

Introduction

Modern day design for the home tends to be a play on one of two existing visual tools – a screen displaying a 2D or 3D representation of your home, where a user can change the position and style of desired items, or screen-based augmented reality for viewing items in space via the camera feed. Additionally, current homes lack the ability for rapid design changes according to mood or style with furniture purchases acting as fixed and finite pieces within the home.

In this work, we wanted to address the above two issues at a smaller scale via a dollhouse – the lack of dynamism & tangibility in current design interfaces as well as our vision for the home of the future. The vision is as follows: Imagine the home of the future, where your space immediately adjusts according to your mood or style. A fully customizable room as such would use projection mapping and would allow for hundreds of styles and thousands of combinations for every surface.

Said dynamic design solution could be created with projection mapping, which would allow for sought modularity. Much work has done been done in this field, from simple projection mapping units [7] to shader lamps [11] to real-time telepresence system [4] to dynamic projection mapping systems [12]. Additionally, work has been done in photochromic materials which would allow for recoloring of 3D printed objects; however, as such is in its infancy, recoloring is not immediate and thus not feasible for our envisioned instantaneous design changes [10].

Inspiration for this project stemmed from an in-house project which used projection mapping on full-scale objects to simulate the catalog of possible texture swatches on a white armchair. As seen in Figure 1, this system delighted users because the interface was invisible – upon first glance, it was only a white armchair, but with projected materials it became a living, changing object. The inevitable next step was to move from this stagnant, viewed experience to an interactive one.

Finally, we wished to investigate the function play has as 'a habitat for collaboration in the context of interior design' by creating an exploratory collaborative tool that removed the barrier of entry for designing one's space [2].

LightSpace: Tangible, Interactive Design

As illustrated in Figures 2 and 3, our dollhouse system is composed of three main elements working in tandem as a dynamic interior design tool: the projection mapping system, optical tracking, and a serial connected microcontroller wand.

Projection Mapping on 3D Printed Objects. The need for our system was derived from a want for a more tangible, yet still dynamic interface that would mimic the current day e-commerce solutions of clicking through fabric options. Spatial augmented reality on 3D printed objects was chosen to allow for this modularity.

Our projection mapping component is based on existing work by Andrew MacQuarry [8]. At a high level, its functionality is derived by using the OpenCV calibrate camera function. To calibrate said system, the user need only feed pairs of point correspondences from the vertices V on the model and points in image space I. This correspondence is hereby referred to as $C=\{m,p\}$, where $m \in V$ and $p \in I$ and lies on the actual location of the physical object represented by m. Originally, we cast a ray from the camera space to the model to collect sample m, but found that this tended to be inaccurate and added calibration error. We devised a way to remove the inaccuracy by creating a known anchor point digitally. This was done by creating an accurate 3D model of the projected areas of the enclosure along with a 3D printed complex shape for additional feature points. At runtime the system would localize these anchor points and store samples of p. With this technique the only manual part of our calibration was the initial setup of the experience -- using the mouse to select the corresponding sequence of p points for each m sample, thus creating a collection of C samples of the same length. Even with human error this style of calibration was very accurate, and it cut down on calibration time by a significant factor.

Optical Tracking. In order to dynamically adjust the system based on the movement on the 3D printed pieces, it was necessary to track each object along the surface. We looked into a number of various tracking methods, namely ArUco markers, Vuforia, ARToolkit, and Vive trackers, and we found all these methods to be lacking with the exception of ArUCo markers [3]. ArUco markers are instances of fiducial, augmented reality markers that can be used for robust detection and pose estimation. For our use, these markers accurately tracked objects visible on the underside of an acrylic sheet covered with 0.03mm semi-matte vellum sheet via a bottom-mounted webcam. The vellum acted as a translucent, low-cost projector film such that we could maintain the feeling of decorating a home by allowing for a projected floor plane, while simultaneously having enough visibility for the aforementioned markers to be seen. We tested the accuracy of markers through various means, including using live visual representations of tracking like js-aruco, as seen in Figure 4.

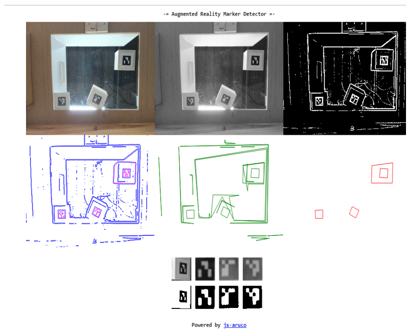

Figure 4: Optical tracking tests via js-aruco

NFC Magic Wand. A vital selling point of our system is the creation of an immersive, tactile, and playful environment for interior design. Necessary for a holistic design experience was a means to easily explore a catalog of material swatches for each object. We ideated between a screen wherein there were limitless options for each piece of furniture and an NFC wand by which one could merely switch forward and backwards through some set, yet unknown options.


Figure 5: NFC Stickers on 3D models


Figure 6: NFC Wand

We found that upon given this choice, users opted for the wand; beyond the context switch from screen to the physical, tangible interface, much of the playfulness of the dollhouse was eliminated by the overwhelming overload of choice and decision fatigue provided by the options on the screen.

Thus, the new, magical interface created was that of an NFC wand with which one could switch textures with a tap on the physical 3D model. As shown in Figure 5, we added NFC stickers to each printed 3D model to allow for individual changes to style. Additionally, we 3D printed a magic wand (Figure 6) containing a small NFC reader that works to query the system and send a serial message according to the NFC tag value found. The combination of these pieces was a new interface by which to communicate with our system of physical objects from simple, existing NFC technology.

Contributions

LightSpace contributes to the current state of art of spatial augmented reality and design interfaces, via the listed features.

Collaborative, Playful Immersion: Current design interfaces involve much context switching; when we design for the home, we switch from looking at a virtual representation of the object we wish to purchase to the physical space we wish to decorate. LightSpace eliminates this constant back-and-forth between screen and physical reality by combining the two.

Interactive Multimodality: With the combination of visual and tangible interfaces, from the utilization of the wand to dynamic, projection-mapped 3D objects, LightSpace supports a new way to design for the home. The interactivity layer separates this system from pure projection mapped systems to become a collaborative, playful interface for design.

Figure 7: Demos

Configurability: The use of spatial augmented reality allows for limitless changes to the textures mapped to each object.

Software Modularity: Our system is built such that it can be used for full-sized pieces in the future.

Conclusion

To our knowledge, LightSpace is a unique means of designing your space, supporting design using visual and tangible stimuli in a physical space. As opposed to previous work focusing on projections on static objects, the addition of dynamism via both moving objects and immediate changes to materials brings us closer to realizing a real-world implementation where projectors in the home are commonplace and changing the appearance of furniture is as simple as a click.

Future Work

Moving forward, there is much work to be done to improve the current system. Though we are able to consistently track objects moving across the page, uneven lighting from the environment can cause inaccuracies and jitter. As such, a next step would be to investigate the potential for non-optical measures to track objects in space, like IR ink markers [9] or other, more complex optical systems [6] [12].

A body of work remains to test the adoptability and scalability of our current interface; a series of user studies would allow us to better understand the advantages and shortcomings of our current framework. Additionally, we would like to implement different means of personalization, such as allowing for user-created textures.

Acknowledgements

This work is supported by Wayfair.

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