Sketching-in-Light: Enabling Hybrid Prototyping of Low-Resolution Lighting Displays

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ABSTRACT
Low-resolution lighting displays are commonplace in internet-of-things devices, wearable products and embedded interfaces. However, prototyping such displays is challenging and cumbersome as methods, specific domain knowledge and skills are only available to experts. In this paper we present a novel toolkit to assist with designing and evaluating the characteristics of low-resolution lighting displays as well as content variations using different materials. We describe the components of the toolkit, which include a tablet, a custom-built app and low-cost prototyping materials, and its use within the context of a design study. The toolkit can easily be replicated and adopted by others working in this domain to prototype low-resolution lighting displays without requiring any previous expertise in hardware prototyping.

Author Keywords
Tangible Lighting-Design, Embedded Low-resolution displays, Toolkit, Hybrid Prototyping.

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Design;

INTRODUCTION

Innovations in light-emitting diode (LED) technology enables the creation of new visual displays that are unique in size, shape, material, pixel arrangement and resolution. Due to the great flexibility, designers from various domains are using digital media as a design material: applications range from wearable LED displays that fit into clothing and lifestyle accessories, wayfinding displays and digital signage, to large-scale architectural structures created of individual pixel elements. These displays are characterized

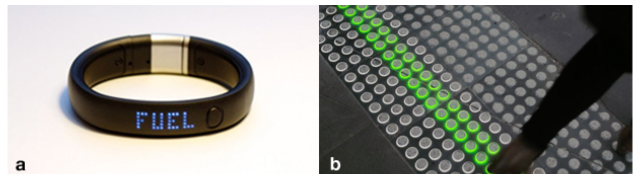

Figure 1. Examples of low-resolution lighting displays in different contexts: (a) Nike+ FuelBand to track and display physicial activities, (b) Ground-embedded traffic light display. Photo credits: (a) © Peter Parkes (licensed under https://creativecommons.org/licenses/by/2.0/) (b) © Büro North.

by their low resolutions, in some cases featuring a complex pixel or three dimensional shape (3D) pattern, and their lighting quality, which distinguishes them from conventional 2D rectangular screens [6]. Depending on the display's resolution and the context in which they are deployed, content can be explicit text-based or abstract (see Figure 1).

As with any design, sketching and creating early prototypes is crucial for "getting the right design and getting the design right" [3]. According to Buxton, sketches should be plentiful and quick to make, while prototypes are important for the iterative refinement of an idea. However, this is still a challenge when it comes to the **creation and representation of content** in the design process of low-resolution (low-res) lighting displays**.** Due to the characteristics of low-res lighting displays, prototyping visual content via conventional digital media displays is not always sufficient. An often underestimated parameter when working with lighting includes **designing lighting as material:** transparency as a material's property can be used to filter or conceal light aimed at influencing the visual experience of low-res lighting displays [5]. To achieve an overall aesthetic result, the material's choice should be included already in early prototyping stages to perform more design iterations along with content explorations. Therefore, appropriate tools are needed to support designers without having an expert knowledge in materials and engineering.

The toolkit presented in this paper, *Sketching-in-Light*, addresses the following limitations of current prototyping approaches: (1) Low-fidelity (low-fi) prototyping methods

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and tools from related fields (i.e., graphical user interface design) cannot be adopted easily due to specific properties, including low resolution and lighting quality. (2) Designers working in this domain therefore have to employ high-fidelity prototyping already early in the design process (i.e., using the *real* components of an eventual design) before having concepts evaluated on a lower level. (3) Doing so results in increased time and cost spent on prototyping, especially if experts from other domains, e.g. electrical engineering, have to be included due to a lack of knowledge in engineering and programming by the design team.

Our toolkit enables:

- Sketching with light on the same level as sketching with paper and pen taking into account a display's specific characteristics.
- *Hybrid* crafting of early designs using physical and digital materials.
- Performing more design iterations fast and at low-cost before the actual implementation.

RELATED WORK

Creating prototypes as early design instantiations for future products is a widely used practice in various design disciplines. For graphical user interfaces (GUIs), designers can choose from a wide range of prototyping methods and tools during different *fidelity* stages of the design process [8]. For example, paper prototyping as a low-fidelity technique is often used in early phases to communicate ideas in collaborative design teams or to evaluate various concepts with users in a time and cost-effective manner [1].

However, since the prototypes' *material* influences the design aspects that can be manifested by a prototype [8], conventional paper prototyping techniques cannot be simply applied to any context. Researchers and designers have therefore begun to develop methods to adapt low-fi prototyping techniques for novel interface domains: Wiethoff et al. created Sketch-a-TUI for prototyping tangible user interfaces (TUIs) using physical objects made of cardboard on a capacitive touchscreen [12]. Broy et al. developed a prototyping toolkit for stereoscopic 3D displays using different depth layers illuminated via a tablet computer as a backlight source [2]. Ullmer et. al presented a physical overlay onto digital pads to create tangible UIs fast and at low cost [11]. In the domain of dynamic, interactive lighting design, Wiethoff et al. presented LightBox [13], a miniature lighting lab to explore content proposals for low-res lighting displays, however, they did not include lighting variations affected by the choice of materiality aspects, as highlighted in our work. In this context, Griffiths stresses the importance of traditional materials in lighting design since "texture, color and patina of materials add to a product's character something that technology is unable to replicate [5]". Within the broader field of interaction design, Robles and Wiberg argue to focus on the materiality of both, the digital and physical, referring to a "material turn" in interaction design [10]. In this vein, we argue that the choice of material should be more carefully considered for low-res lighting displays and reflected in prototypes, which is not feasible when working solely with digital artifacts as a simulation source. Further, we propose hands-on crafting techniques in this domain, incorporating the idea of "*hybrid crafting"*, defined by Goldsteijn et al. as "everyday creative practice of using combinations of physical and digital materials, techniques or tools [4]".

SKETCHING-IN-LIGHT

Our toolkit *Sketching-in-Light* is intended for building mock-ups of low-res lighting displays. It allows designers to create visual content using a large variety of physical and digital materials we refer to as tangible lighting design (TLD). The prototyping steps include (a) **Physical Sketching**, which involves painting and crafting with translucent materials on tracing paper, (b) **Configuring the Display Mock-up** using various physical overlays, including the inserted sketch, (c) **Hybrid Prototyping** by attaching the display mock-up onto a digital tablet serving as a light source and animating the sketch with configurable light patterns. For overview purposes, the prototyping steps are described in the above-mentioned order, however, the actual prototyping activities reinforce each other and can be carried out iteratively.

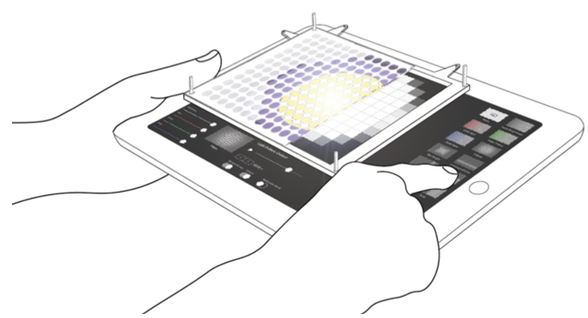

Figure 2. Hybrid prototyping environment including a digital tablet augmenting a display mock-up with dynamic lighting patterns.

a. Physical Sketching

Drawing and sketching by hand is a powerful technique that is widely used by interaction designers to express and discuss early ideas [1]. However, digital painting applications provide only a limited number of input devices, such as mouse or stylus. In comparison, there is a large variety of materials and tools that can be used for making things in the physical world [7]. For *Sketching-in-Light*, we therefore augment the digital sketching canvas with physical materials, creating a *hybrid* prototyping environment. The use of physical materials allows designers to experiment with various tangible materials that offer transparent or translucent qualities, such as watercolor paints, water based ink, colored silk paper and cellophane foil which have not yet been included in lighting design. These tangible materials further enable a wide range of crafting activities, such as painting with a brush, drawing and sketching with a pen, as well as creating a collage by

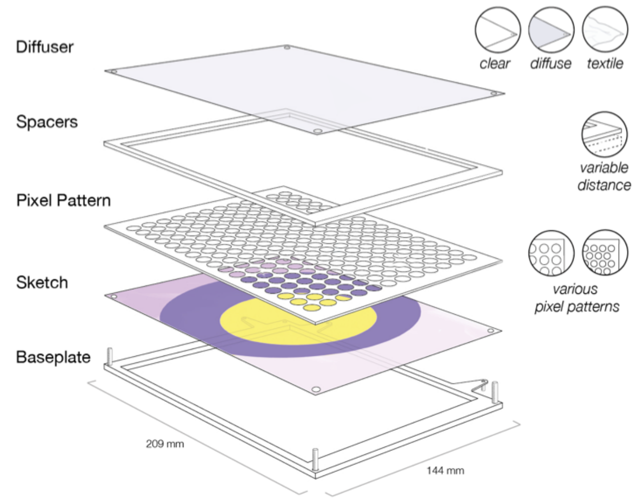

Figure 3. Example configuration of the display mock-up.

cutting out and assembling shapes. As *support material* we used DINA4 Canson Tracing Paper Pads with 90gsm paper weight. Due to the non-opaque properties of all materials used, the sketch can be illuminated and animated through a digital tablet as a backlight source (described in step c). To see the final effect of the illuminated display, the sketch can be directly designed on top of a digital tablet[1], similar to commercially available tracing boards.

b. Configuring the Display Mock-up

As any low-res lighting display comes with unique features in terms of resolution, pixel configurations and materials, we created physical overlays to simulate different *pixel patterns* and *lighting qualities*. The laser-cut overlays are all freely-available as templates[2] consisting of a baseplate, pixel pattern sheets, spacers and diffuser sheets (see Figure 3). All templates measure 209x144 millimeters, adjusted for the use with an Apple iPad Pro (12.9 inches). For the baseplate (3mm black acrylic), nylon screws (M2 x 16mm) are bolted onto the plate to stack up the perforated sketch and overlays. For a better alignment with the top-left corner of the iPad (see Figure 2), the baseplate has three tabs with nylon screws facing down. To simulate various pixel configurations and shapes, we designed pixel pattern templates that can be easily modified. For our initial use case, prototyping an ambient lighting display, we laser-cut a grid system with 17x12 circular holes from 0.8mm white opaque polypropylene. Cutting the pixel sheets from other materials (e.g. black opaque, etc.) can be used to increase the lighting contrast. Further, our toolkit allows to experiment with *diffusion* which is a critical parameter influencing the lighting quality [5]: we therefore assembled sheets from polypropylene (clear and translucent) as well as *spacers* to easily change the lighting diffusion. The physical overlays aim to stimulate designers to experiment with materials (e.g. translucent textiles for wearables) along with content, while keeping in mind that they do not necessarily represent the actual light quality of the finished product.

c. Hybrid Prototyping

In the final prototyping step, designers can use our toolkit to illuminate the physical display mock-up (see Figure 2). Similar to [2], we use an iPad as a background light, however, with additional user interface (UI) control elements (see Figure 4) to augment the display mock-up with lighting effects and other digital media (e.g. images). Therefore, the toolkit app[2] is divided into a background lighting area on top of which the display mock-up is placed (see Figure 4a) and control elements below and on the right hand site. The virtual pixel grid is aligned with the pixel pattern sheet described in section b. For other display configurations the grid must be edited within the code. With the controls on the right-hand side (see Figure 4b), users can choose from a list of i) predefined lighting patterns and ii) options for customizable content. With the controls in the lower left-hand section (see Figure 4c), users can adjust hue and brightness as well as playback settings (e.g. speed, forward/backward, fading, etc.). In the lower right-hand section (see Figure 4d), users can find context-sensitive controls when a customizable content option is selected.

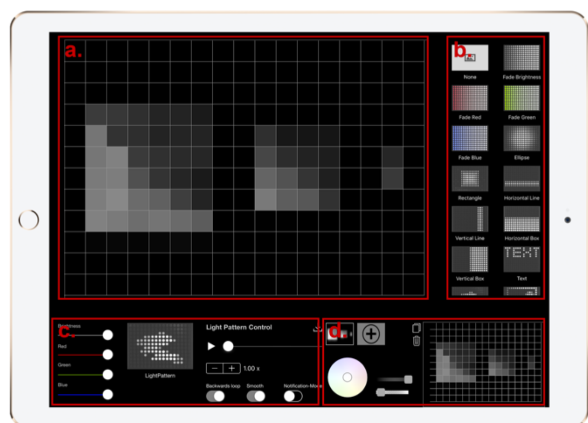

Figure 4. Sketching-in-Light toolkit application: (a) area for placing the display mock-up, (b) list to select from lighting patterns and content options, (c) playback settings, (d) controls for the customizable content (here the drawing tool selected).

In total, we implemented eight predefined lighting patterns that are defined by changes in *color*, *brightness* and *pixel position*. These variables were chosen based on previous research evaluating lighting patterns for low-res lighting systems [9]. Further, the set is supplemented by a drawing tool to create customized lighting patterns through simple key frame animations. The drawing tool (selected in Figure 4) can be used by two means: either animating the hand-crafted sketch drawing directly onto the tracing paper which does not impair the functionality of the touch screen, or creating "digital only" animations onto a small-scale

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[1] To protect the screen we used glass screen protector foil with 9H hardness (mohs scale of mineral hardness).

[2] https://hoggenmari.github.io/Sketching-in-Light/

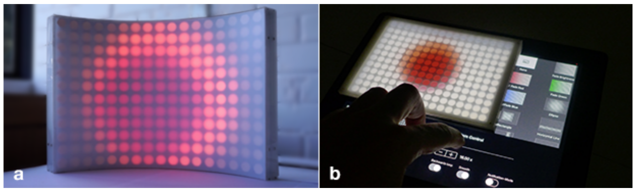

Figure 5. (a) Hi-fi prototype of the ambient light display (b) Low-fi prototype using *Sketching-in-Light*.

preview screen while the display mock-up is placed on the iPad. For prototyping text-based content, we implemented a 4x5 pixel font including alphabetic and numeric characters; text messages and scrolling options that can be edited by the user. Furthermore, users can pick images from a photo library that are subsequently mapped onto the pixel grid. This enables the use of the internal camera or previously saved online content as a source.

Finally, we developed a Java-based library to allow for the development of visualizations in Processing[3]. Using this library, the visual output from the Processing sketch can be directly displayed on the toolkit app, thus using the physical display mock-up as an output medium. Providing such a physical development environment in lighting design, our toolkit enables users to move from initial sketches to initial implementations without requiring the final hardware.

USING SKETCHING-IN-LIGHT IN CONTEXT

In collaboration with a small company in the smart home sector, we used *Sketching-in-Light* in an industrial context for the conceptual design of an ambient lighting display visualizing the performance of residential solar panels. The project used an existing pre-production prototype made of high-power RGB LEDs, round reflectors, diffusor film and a curved shape (see Figure 5a). To design the display visualizations we created a display mock-up using a 17x12 pixel pattern and a diffusor sheet with 3mm spacers to simulate the actual ambient lighting display. The scale of the display mock-up was approximately 1:2.5. Although the mock-up did not have the curved shape of the high-fidelity prototype, the augmented display mock-up (see Figure 5b) provided a realistic impression of the actual display in terms of resolution and smoothness of colors.

During a workshop session, we made our toolkit available to the company's product team to create design proposals for the visualization of solar and electricity performance data. Workshop participants were able to easily move between the three prototyping stages, using physical and digital materials. They also adopted the toolkit in unintended ways, such as expressing dynamic content through physical materials by manually moving silk paper cutouts back and forth behind the display frame. The workshop participants found our toolkit to be a valuable design tool as it enabled them to create and explore content variations for a new medium. Following on from the workshop, we were then able to implement and evaluate some of the proposed visualizations using our custom-developed Processing library.

DISCUSSION

The *Sketching-in-Light* toolkit extends previous work by integrating crafting and combining physical and digital materials. This approach offers designers to fluently move between sketching and prototyping [3] across various levels of fidelity. Working with physical materials allows the iterative exploration of conceptual ideas in a time and cost-effective manner. Through the digital tablet application, designers can refine their prototype and fine-tune its visual appearance and dynamic behavior. Going back and forth between the stages of physical sketches and hybrid prototyping, we consider our toolkit as a *supportive enabler* for creating and exploring early ideas in the design process of low-res lighting displays.

Limitations. Simulating low-res lighting displays without actual hardware comes with several limitations: using a digital tablet as a backlight source does not provide the same brightness levels as high-power LEDs and the evenly illuminated tablet surface differs from the punctual lighting sources produced by single LEDs. Further, the flat, rectangular shape of the tablet restricts prototyping of 3D display shapes, such as the curved ambient lighting display used in our design workshop. Some design decisions (e.g. display format, pixel pattern) were based on this existing ambient lighting display used in the workshop. In its current version, the toolkit requires programming to adapt the toolkit to other dimensions and pixel grids. To remove this limitation, we are planning to further develop the toolkit application to support customized pixel configurations based on the created template.

Benefits of Sketching-in-Light. We consider the following advantages that stimulate the design process by having a toolkit for fast and low cost exploration of visual experiences of lighting displays along with content:

- Our approach is easy to replicate for others.
- There are no additional lighting components required.
- It provides the ability to simulate specific characteristics of displays such as pixel configurations and lighting qualities.
- Fluid use of physical and digital materials.

CONCLUSION

Designing with low-resolution lighting displays comes with several challenges, one being that prototyping still demands a high level of technical expertise and low-fi prototyping methods are hardly available in this domain. We therefore presented a prototyping toolkit to create content for low-res lighting displays proposing the use of various materials. The toolkit can be used by designers without requiring any

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[3] https://processing.org

skills in hardware prototyping. It can also be used in co-design sessions with prospective users or other stakeholders, facilitated by designers. We described the use of our toolkit in a real-life context with a potential user group that could benefit from such low-cost and easy-to-use tools. We hope that our toolkit will enable designers of low-res displays to test out multiple display configurations and content variations early in the design process, leading to more aesthetic and enjoyable products.

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REFERENCES

1. Mark Baskinger, M. Cover story: Pencils before pixels: a primer in hand-generated sketching. *Interactions 15,*2 (Mar. 2008), 28-36. http://doi.acm.org/10.1145/1340961.1340969
2. Nora Broy, Stefan Schneegass, Florian Alt and Albrecht Schmidt. Framebox and mirrorbox: Tools and guidelines to support designers in prototyping interfaces for 3D displays. In *Proc. CHI 2014.* http://doi.acm.org/10.1145/2556288.2557183
3. Bill Buxton. Sketching User Experiences: Getting the Design Right and the Right Design. *Morgan Kaufmann,* 2007.
4. Connie Golsteijn, Elise van den Hoven, David Frohlich and Abigail Sellen. Hybrid crafting: towards an integrated practice of crafting with physical and digital components. *Personal and Ubiquitous Computing 18, 3 (2014), 593-611.* http://dx.doi.org/10.1007/s00779-013-0684-9
5. Alyn Griffiths. 21st Century Lighting Design. Bloomsbury Visual Arts.
6. Kim Halskov and Tobias Ebsen. 2013. A framework for designing complex media facades. *Design studies 34(5).* http://dx.doi.org/10.1016/j.destud.2013.04.001
7. Mami Kosaka and Kaori Fujinami. UnicrePaint: Digital Painting through Physical Objects for Unique Creative Experiences. In *Proc. TEI 2016.* http://doi.acm.org/10.1145/2839462.2856553
8. Youn-Kyung Lim, Erik Stolterman and Josh Tenenberg. The anatomy of prototypes: Prototypes as filters, prototypes as manifestations of design ideas. In *Proc. TOCHI 2008.* http://doi.acm.org/10.1145/1375761.1375762
9. Andrii Matviienko, Vanessa Cobus, Heiko Müller, Jutta Fortmann, Andreas Löcken, Susanne Boll, Maria Rauschenberger, Janko Timmermann, Christoph Trappe, Wilko Heuten. Deriving Design Guidelines for Ambient Light Systems. In *Proc.* MUM 2015. http://doi.acm.org/10.1145/2836041.2836069
10. Erica Robles and Mikael Wiberg. Texturing the "Material Turn" in Interaction Design. In *Proc. TEI 2010.* http://doi.acm.org/10.1145/1709886.1709911
11. Brygg Ullmer, Christian Dell, Claudia Gill et al. (2011). Casier: Structures for Composing Tangibles and Complementary Interactors for User Across Diverse Systems. In *Proc. TEI 2011.* http://doi.acm.org/10.1145/1935701.1935746
12. Alexander Wiethoff, Hanna Schneider, Michael Rohs, Andreas Butz and Saul Greenberg. (2012). Sketch-a-TUI: low cost prototyping of tangible interactions using cardboard and conductive ink. In *Proc. TEI 2012.* http://doi.acm.org/10.1145/2148131.2148196
13. Alexander Wiethoff and Magdalena Blöckner. Lightbox: exploring interaction modalities with colored light. In *Proc. TEI 2011.* http://doi.acm.org/10.1145/1935701.1935799