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Exploring a Textile-based Shadow Lamp Display Incorporating Shape Memory Alloys

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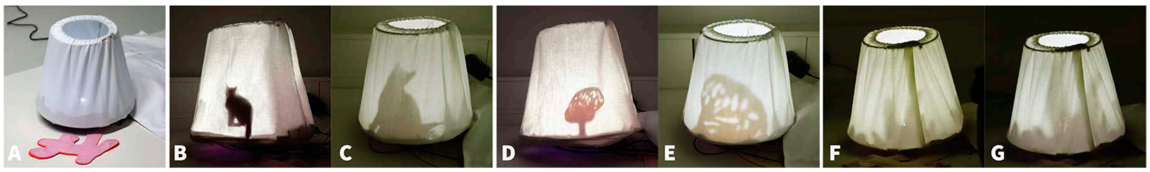

Fig. 1. Shadow Lamp. (A) Shadow lamp setup used in the user study (B) Shadow 1 -iconic cat - in sharp state; (C) Shadow 1 in blurred state; (D) Shadow 2 -abstract- in sharp state; (E) Shadow 2 in blurred state; (F-G) Shadow 3 -abstract- in different elevation states

This paper explores a novel concept of textile-based shadow displays that incorporates shape memory alloys (SMA) on fabrics to cast dynamic shadows as an ambient information display. To explore this, we implemented a lamp prototype, capable of presenting a set of dynamic shadows. These shadows exemplified *iconic* vs. *abstract* shadow figures, as well as demonstrating changes in *shadow sharpness*, *size* and/or *position* on the lamp's shade. We conducted a user study (n =8) to investigate the perception toward our concept. Our findings report that the concept does not only provide the potential for a variety of use cases, dynamic alterations of the shadows feel like a decorative addition to the living spaces, as well as creating relaxing channels of information display.

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

Additional Key Words and Phrases: Textiles, Shape Memory Alloys, Shadow, Ambient Display

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1 INTRODUCTION

With the rapid developments of technology, we get exposed to an immense amount of information and notifications in our everyday lives. As a response to this situation, the HCI field shifts its focus from conventional graphical user interfaces and notification devices to ambient displays (ADs) to represent information embedded in the architectural spaces. Unlike traditional user interfaces, ADs allow rich aesthetic experiences that take advantage of sensory aspects of the physical space [27]. They are more domain-specific and designed not to require constant attention.

In that direction, we see a potential in using shadows as subtle displays of information and notifications. Shadows are an integral part of our everyday lives. We are intuitively aware of the shadows as by their very nature always present, yet unobtrusive, in our surroundings. Functional uses of shadows are apparent in human history, i.e. with sundials [21] and shadow puppetry [6]. In modern world, we design intentional manipulations in lights and shadows in the living spaces, not only for functional needs such as the adaptation of different lighting scenarios, but also creating aesthetic marks on the environment. Leveraging the computerized opportunities around utilizing dynamic shadows within the living spaces, a few studies utilized dynamic shadows with decorative pieces as ADs (i.e. [3, 19]). Yet, how shadows could be used for displaying ambient information still merits further research.

In this paper, we explore the design of a textile-based shadow display in the form of a desktop lamp. The combination of textiles and computable materials (i.e. conductive threads and muscle wires) has been explored and proved to provide a seamless merger and reliable material composites for interactive products when traditional fashion production techniques such as weaving, sewing are applied [16]. Our study aims to utilize sewing and stitching computable materials on textiles to explore an alternative use case by creating dynamic shadows as an ambient display. In this regard, our design explorations focused on combining muscle wires with textiles to create dynamic shadows. Muscle wires are materials in the shape memory alloys (SMA) category, that remembers and switches to a previous shape when power is applied [17]. We chose muscle wire because when compared to other physical actuation techniques (i.e. with servo motors), SMA's enable subtle shape changes in a silent manner. This is aligned with our aim to use shadows as ambient displays where the information is presented in a non-intrusive way, enabling the user to attend information with their will instead of alerting them [15]. Using the combination of SMAs and textiles for casting shadows on the environment is previously demonstrated by a few previous works [3, 22]. However, different from these , our lamp does not rely on finding flat surfaces in the environment for casting clear shadows. Instead, it uses a stable surface on the lamp itself, the shade. We believe exploring such form-factor, that also leverages subtle movements of SMA for casting dynamic shadows, could be handy for understanding the informative capacity of shadows.

By examining the parameters like the distance of the textile silhouettes in relation to the shade of the lamp and the light source, we implemented a prototype that is capable of showing three dynamic shadow alternatives on its shade. These alternatives exemplified *iconic* vs. *abstract* shadow figures, as well as demonstrating changes in *shadow sharpness*, *size* and/or *position* on the lamp's shade. To explore the AD potential of our shadow lamp concept, we conducted face-to-face focus group studies with 8 participants in total. Here, we present the design process, implementation, and user study results of our shadow lamp concept.

2 RELATED WORK

With the increasing amount of information and notification, more devices start competing for our attention. HCI researchers have previously introduced the concept of AD which does not require our full attention and allows unobtrusive displays to convey information. Wisneski et al. [27] introduced the concept of ADs through their ambientRoom and ambient fixtures concepts. ADs have been a prevalent research topic for over a decade. In addition, Mankoff et al. [15] presented an evaluation method for the comprehensive assessment of ADs. Previous examples in the area include aesthetic objects designed to be used for information display in private and public spaces. For example, Kuribayashi & Wakita [13], in their novel concept PlantDisplay, utilize houseplants to present information as a natural ambience. A similar approach was also taken by Voit et al. [24], exploring the light cast on a living plant to communicate non-urgent

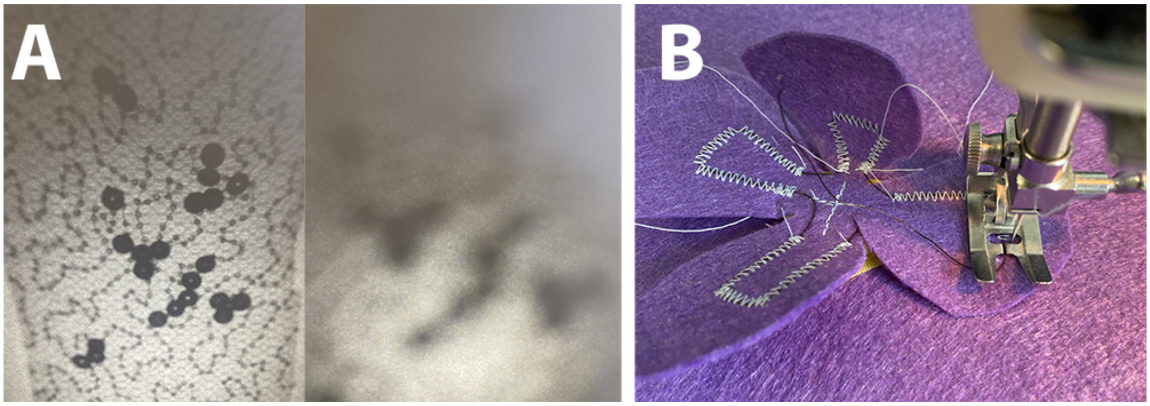

Fig. 2. (A) Blurred and sharp states of an abstract figure; (B) Sewing the muscle wire on the felt for Shadow 3.

notifications, whereas Fuentes, Rodriguez and Herskovic [9] implemented an artificial tree with leaves that light up to convey communication frequency. Lamps were also considered to have a potential for ambient information display. Fortman et al.'s [8] MoveLamp, where information is embedded into an everyday object to help increasing office workers' physical activity during a typical working day. Cha et al.'s [2] Gleamy lamp is an AD that aesthetically conveys information through the changing optical elements e.g. transparency and opacity that occur in the shade of the lamp. Voit et al. [25] also explored a smart light as a part of a smart calendar platform, conveying information about an upcoming event by changing color. Other than smart lights, researchers also experimented with interior design elements such as interactive windows [1] or doors [26] to present ambient information.

There have been a few works exploring the use of shadows as information-carrying elements. Häkkilä et al. [10] introduced a prototype of a candle shadow display, which utilizes text messages to display different emoji-style images. Jensen et al.'s [12] ShadowLamp utilized shadows projected on a bedroom ceiling to enhance bedtime storybook reading. Recently, Colley et al. [4] presented an AD concept that explored manipulations of a plant shadow display. Cowan et al. [5] utilized shadows created by the user's hands as an input mechanism. Raudanjoki et al.[20] explored human shadow displays, where manipulated human shadows were created for information display purposes. A more recent work, ShadowSparrow[19], a desk lamp that utilizes light and shadow designed to create an alternative channel for information delivery in the home or work environment. Jensen et al. [11] examined the potential of ambient shadows, projected from a lamp with a transparent display manipulating the shadow, in dialogic reading. The shadows created by users occluding the lightboxes while interacting with them also explored in the context of art and performance [23]. Here, Lucero et al. [14] point out interactive lights (and shadows) as an effective modality for information displays. Yet, they also suggest future work to examine the semantics of light and how people perceive them in different situations.

While various technologies were presented in prior works, SMA's are rarely considered for manipulating shadows. One example is Shutters [3] which is a curtain composed of controllable louvers with SMAs for casting shadows as an information display. Another example, Lotus Dome [22], is a concept that uses SMAs for controlling the cutouts on a dome as the viewers approach with their hands. Different from these prior works, in our work, we utilized the combination of textiles and SMAs to cast shadows on a lamp's shader, instead of relying on flat surfaces around.

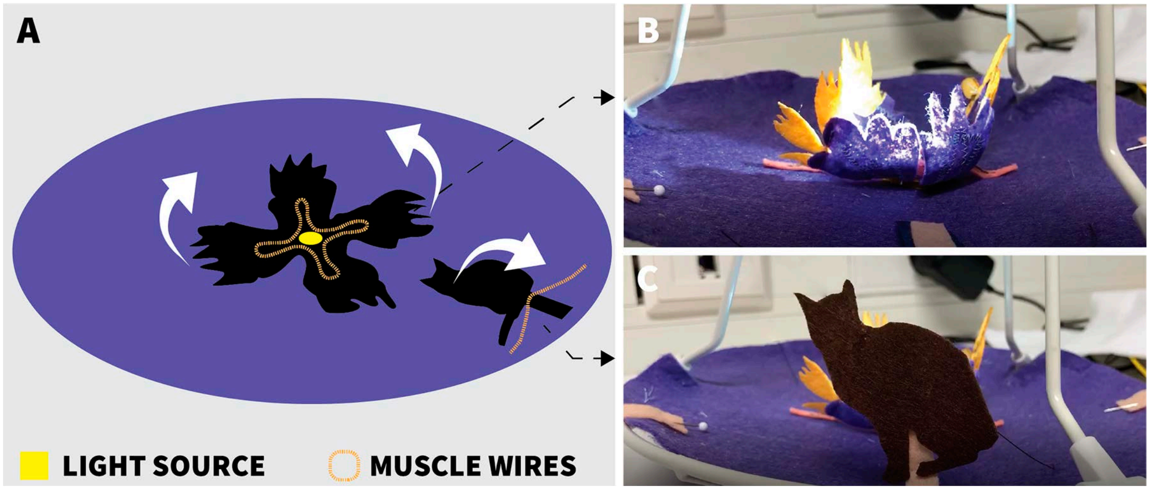

Fig. 3. (A) The working principle of the shadow lamp, showing Shadow 1's and Shadow 3's switching mechanisms; (B) Shadow 3 cutouts elevated; (C) Shadow 1 cutout risen up.

3 CONCEPT & IMPLEMENTATION

We started our explorations for a textile-based shadow lamp with muscle wires and textiles. We chose this combination as muscle wires are capable of creating slow, organic and silent movements by contracting and/or expanding textiles [7]. We tested such effects by creating cutouts with lightweight textiles (polyester-based mesh fabric and felt) and moving them between the light source and the screen. For instance, Figure 2-A shows how a textile piece can move in the lamp to switch from a blurred state to a sharper state when the fabric piece moves closer to the lampshade. Eventually, we noticed that we can play with the sharpness, size, and location of the shadows on a screen.

Upon the first exploration, we focused on a concept of a shadow lamp (Figure 1) to demonstrate and examine the perception towards different dynamic shadows featuring as an ambient display. We chose a relatively small desktop lamp form factor with a standard conic shade to enable the usage in various contexts such as on a working desk, nightstand and dining table. In this concept, a bright light source is occluded by textile cutouts (*abstract* and *iconic figures*), see Figure 3, that are moved by muscle wires and cast dynamic shadows, alternating qualities like *sharpness*, *size* and *position* on the lamp's shade.

- *Shadow 1* (Figure 1-B-C) uses an iconic representation with a cutout of a cat made from polyester felt. During the experimentation phase, we tried other iconic representation alternatives, such as heart, smiley and star, that are commonly used in conventional user interfaces. However, we found the cat figure more relevant to shadow displays, as the shadows of actual objects and living things are natural to observe in real life. In this regard, we were curious about the perception towards utilization of a relatively realistic shadow as ambient displays. In Shadow 1's first position, the cutout fabric piece lays flat on the base of the lamp near the shade (Figure 3-A). When the muscle wire embedded in this piece is activated, the silhouette rises up (Figure 3-C). As it comes closer to the shade, a shadow of a cat gradually appears and becomes sharper. After the first appearance, the shadow slightly transits between sharp and blurred, as well as big and small states without disappearing from the shade.

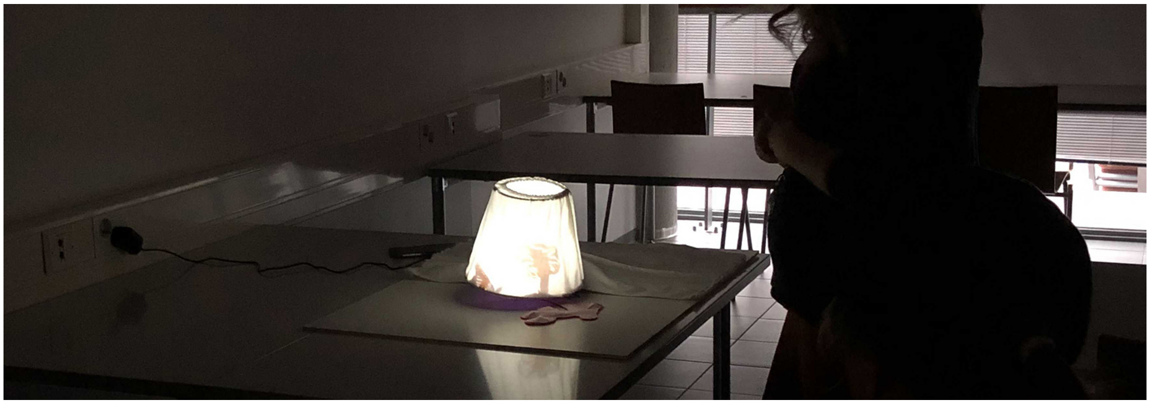

Fig. 4. User study setup, moderator demonstrating the shadows to two participants

- *Shadow 2* (Figure 1-D-E) incorporates the same mechanism, but instead of the cat silhouette, the cutout is shaped as an abstract pattern. Here, we intentionally created an ambiguous shape that does not resemble any known object as we were curious about how it would be interpreted by the viewers.
- In a similar ambiguous fashion to shadow 2, we created abstract cutouts for *Shadow 3* (Figure 1-F-G). Different from the prior alternatives, these cutouts were sewn around the light source. They are elevated by pulling the muscle wires attached to the fabric, casting blurry shadows that move up and down on the shade depending on whether the muscle wires are activated or not.

The shadow lamp display is operated by an Arduino Microcontroller (UNO) with an Arduino Motor Shield (Rev3) that has two high current outputs suitable for activating muscle wires. Two muscle wires used in the prototype are a feet-long SparkFun Accessories Muscle Wire with a diameter of 0.012 inches. For, Shadow 3, we trained one of the muscle wires by wrapping it around a screw and heated it up with a heat gun to high temperature as the instructions of the muscle wire suggested. By using a sewing machine, the trained wire was sewn on a laser-cut felt (Figure 2-B). This enabled the wire to remember its wrapped state, thereby pulling and rising up the loose sides of the cutout when a current is applied (Figure 3-B). Figure 3-A illustrates the implementation we used for Shadow 1 and 2: For these, the second muscle wire's two ends are fixed on the side of the base. The mid-point of the wire is stitched on a rectangular-shaped piece of felt that acted as a base to fix iconic cat and abstract pattern pieces for casting Shadow 1 and 2. The other end of this base piece was anchored on the side of the lamp's base. Here, we used tape to attach felt cutouts for Shadow 1 and 2 to this base with the purpose of easing up the process of changing cutouts in the user study. This setup enabled us to demonstrate the movements of Shadow 1 and 2: When a current is applied, the second muscle wire straightens and causes a rise at the unanchored side of the base felt piece (Figure 3-A-C) and shadow appears. After the first appearance of the shadow, the voltage is cut and the felt piece slightly pulls itself down. It rises again when the wire is activated and the process repeats yielding a breathing-like movement. As the light source, we used a small high-power LED (1W) which provides focused light for creating sharp shadows. This LED was attached to the center of the lamp base. To enable the control of each muscle wire, as well as turning on/off the light, we included three push buttons that are hidden under pink cotton textile next to the lamp.

4 USERSTUDY

To explore the perception towards different dynamic shadows created we conducted a user study (Figure 4). As a suitable method to evaluate the shadow lamp display concept, we arranged a focus group. We invited 8 participants (4 female, mean age was 30.5) in total and the study was conducted with two participants at a time.

The sessions were facilitated by one moderator and an observer who took notes. The session started off collecting the written consent of the participants. After a short introduction to the study, participants logged in to the online questionnaire form and completed a short background questionnaire. The moderator then presented the three shadow alternatives in turn by pressing the allocated buttons that activate the muscle wires. After each demonstration, participants were encouraged to discuss then they individually provided their views on an online questionnaire through their mobile devices. For each shadow, the online questioner involved an open-ended question *"What could this shadow show?"* and 5-point Likert scales for two parameters (*visibility of state and intuitiveness*) that were extracted from Mankoff et al.'s AD heuristics [15]. At the end of the shadow demonstrations, participants were encouraged to explore the displays by themselves. Finally, they were asked to fill in the final part of the survey. This part involved a 5-point Likert scale asking *"How did they like the shadow lamp concept?"*, locations to use the concept, as well as positive and negative aspects of the lamp. Each focus group lasted approximately half an hour.

5 RESULTS

5.1 Quantitative Results

In general, participants were positive towards the concept of shadow lamp (see Figure 6). In terms of *visibility of states*, the mean quantitative ratings for noticeability were all around the acceptable, neutral range (Figure 5). Here, the exception was Shadow 1 that is rated slightly more noticeable than the others. This might be due to the distortion of the cat figure being more noticeable than the abstract shadow alterations in Shadow 2 and 3. In terms of *intuitiveness*, all shadows were rated slightly below the neutral (Figure 5), suggesting that, as also vocalized by P3, the meanings of the shadows were unclear without learning.

5.2 Qualitative Results

5.2.1 Meanings of Dynamic Shadows. The slight movements and changes in abstract shapes (the Shadow 2 and 3) reminded participants of the movement of objects in nature (N=5). P1 thought that the pattern growing in size in Shadow 2 resembles a plant opening its leaves. An object moving in the wind was another nature phenomenon highlighted for Shadow 2 and 3 (N=4). The movement of these shadows was associated with environmental info such as apartment temperature, weather, time of the day. Furthermore, specific to Shadow 2, P1, P3, and P8 mentioned plant health might be a type of data shown by the lamp since this abstract shadow looked like a plant inside the lamp. Finally, the slow movement of Shadow 3 was found calming by P5 and P8 that this shadow makes them think it is a reminder to relax.

On the other hand, a few participants (N=3) indicated growing movement of the shadows, when they are associated with animals, can be perceived as spooky. This was the case for Shadow 1 and Shadow 2. Referring to Shadow 1, P2 explained *"At first it was great, a cute cat! But when it was moving, it was like in a horror movie, the figure coming closer and changing shape and looking disfigured on the top."* P1 suggested this shadow alternative might be used to indicate *"some sort of threat level"*. Also, highlighting the resemblance of the vertical movement of Shadow 3 to *"tentacles pulsing or spider or a hand coming out"*, P2 commented this movement can be *"cool or scary for the kids"*. Despite the spooky feelings associated with shadow movements, participants also highlighted the potential of moving shadows

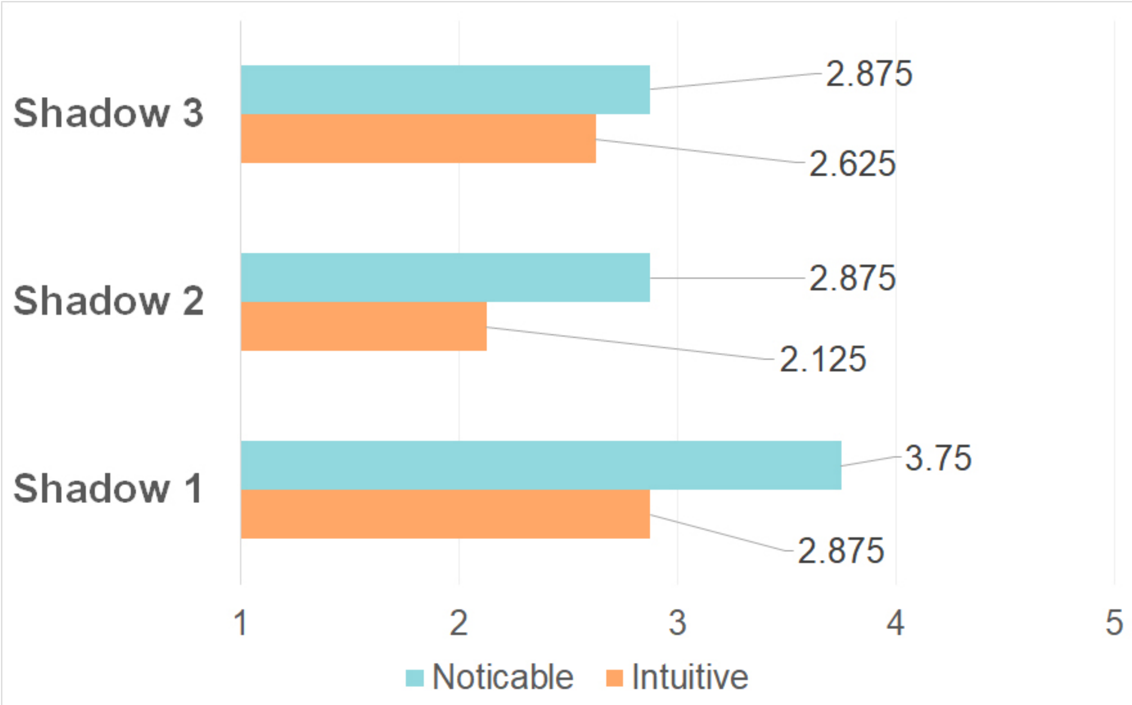

Fig. 5. Mean participant ratings for the visibility and intuitiveness of each shadow

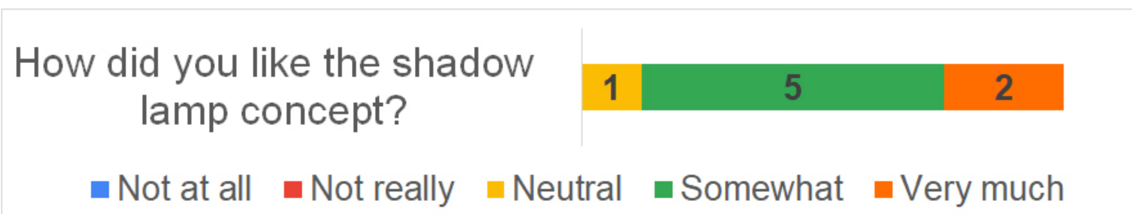

Fig. 6. Participant's rating of the shadow display concept

in supporting bedtime storytelling for kids (N=3), as well as accompanying stories or poems for adults (P7). Here, P1 suggested artistic design might lessen the creepy feeling.

Furthermore, iconic shadows appearing on the shade, as in Shadow 1, were perceived useful for reminding daily chores such as parents coming home (P2), what to buy from supermarket or pharmacy (P6), or express social media activity (P5). Instant presence of abstract figures in Shadow 2 and 3 was also suggested for similar indications, i.e. notifying the dishwasher is ready (P3). On the other hand, P6 commented on the challenge of understanding what the abstract figure in Shadow 2 represents and suggested it could indicate an encrypted message from someone to the user.

5.2.2 Dynamic Shadows as Relaxing and Decorative Display. The qualitative feedback on dynamic shadows suggests that participants favored the calm way the information presented on the shadow lamp (N=5). P5 highlighted "it's not an aggressive way to deliver notifications." Here, P7 appreciated the slow movements of the shadows: "In case the shadows would be too quick, it could be annoying, but here in this case the velocity was good." Also, participants (N=4) highlighted the relaxing effect of receiving information with the slow shadow movements. Regarding this, P5 suggested the shadow lamp could be situated next to the bed as, for her, "it would be fun to have some kind of indication on the day when I wake up, in a gentle way. Like the weather, how busy the day will be, am I already late, etc.". Apart from the relaxing effect, the lamp's potential positive addition to the living spaces was another topic of conversation (N=3). For example, P7 raised her desire "to use it as an evening lamp for myself to create mood in the living room." In this regard, the shadow lamp's decorative aspect was also considered as an aid to sleeping in the bedroom (N=3).

5.2.3 Suggested Improvements. A vocalized challenge of the shadow lamp was the visibility of the shadow states, especially when they move slowly in a small lampshade surface. Although the participants enjoyed the calm movements of the shadows for the representation of information on the lamp, half of the participants (N=4) highlighted the challenge of noticing these movements. For this, P1 and P2 suggested making the lamp, as well as the shadows, bigger. P1 also indicated the shadows might be cast on the walls instead of the lampshade. Other than visibility, P2 foresaw that "maybe some kids would like to custom make shapes." and wished that the user could change the shadow silhouettes easily.

6 DISCUSSION & CONCLUSION

We address the topic of ambient displays utilizing shadows to carry information in a home or work environment designed as decorative and functional objects. In our concept, we focus on realistically distorting the shape of shadows to create dynamically moving variations of figures. Differing from the previous examples, we utilize SMA to create organic and calm effects by computing the textile-based cutouts. With this setup, we designed, implemented and evaluated a shadow lamp prototype demonstrating dynamic shadows for conveying ambient information and notifications.

In this regard, our design process and final prototype introduce useful design parameters that can be played with while future researchers and designers explore the design space of the shadow-based ambient displays. First of all, our shadow alternatives highlighted how optical properties of shadows can be experimented with by embedding muscle wires on occluding textiles to move them relevant to the light source and lamp's shade. For these types of state changes in the shadows, our work demonstrated *shadow sharpness*, *size* and *position* as design parameters to be explored. For example, Shadow 1 and 2 exemplify how designers can vary the voltage fed into the muscle wire to enable back and forth transition from a blurry and bigger state of the shadow to a smaller and sharper one: When voltage is applied the muscle wire extends and the fabric is elevated, moving closer to the shade. When the voltage is cut, the fabric's weight pulls itself away from the shade. Furthermore, while Shadow 3 demonstrates the blurry state of the shadow by situating the occluding textile away from the shade, this alternative also makes use of voltage alteration to change the position of the shadow on the shade moving up and down. Apart from these temporality parameters, our explorations also revealed representational fidelity [18] as a viable parameter to experiment when it comes to designing dynamic shadows as ambient displays. Here, our prototype exemplifies *abstract* (Shadow 2 and 3) and *iconic* (Shadow 1) representations that can be created by designing the shape of textile cutouts to occlude light. Although in our study, the final implementation of iconic figures was limited to a shadow of a cat figure, we can imagine this parameter can be examined with other iconic figures such as a smiley and heart icons, as well as other realistic representations such as a human or a dog figure.

Based on the results of our user study, textile-based shadow lamp display appear to be a viable solution for the ambient display of notification and information. The study results suggest that the meanings of *abstract shadow figures with small dynamic alterations* (Shadow 2 and 3) were mostly associated with the movements of objects in nature and found useful for conveying environmental information. As also highlighted by the participants, a future use case for this kind of dynamic shadows can be on a bedside lamp, communicating the weather situation outside or time of the day. Here, the changing position of the abstract shadows on the shade (as in Shadow 3 moving up or down on the shade) can indicate the time of the day, whereas the speed of the breathing-like temporalities from blurry and bigger shadows to smaller and sharper state (as in Shadow 2 after its first appearance) can indicate how windy the day is or will be. Moreover, our results suggest that *dynamic alterations of iconic shadows*, when they are associated with animals, can be perceived as spooky and can be used to indicate *"some sort of threat level"* (P1). This perhaps also tied with the presentation of shadows in art and contemporary media as an element of scaring the audience. An example of this is apparent in the movie called Monsters Inc., in which the distorted shadows of, otherwise cute, creatures are introduced as a scary element to the audience. However, as some participants also highlighted, the direct visual resemblance of iconic shadows to existing objects or UI elements can still be easy to interpret as an ambient notification. Based on this, as a future use case, we can name a desktop lamp, placed on a desk where the user works or studies. This lamp can convey notifications with iconic shadows appearing or switching from a blurred state to a sharper one (as in Shadow 1). For instance, a shadow of a thumbs-up icon can indicate social media activity, or a cutlery shadow icon can notify the dishwasher is done. Participant feedback also suggests that the slow and organic dynamicity in shadow forms also feels like a decorative addition to the living spaces while creating a relaxing channel for information displays.

On the other hand, our concept still raised some common challenges, apparent in ambient displays like the need to learn the display's meaning or visibility of change [15]. Here, we note that, although in terms of intuitiveness, our study pointed out possible meaning associations with different dynamic shadow alternatives, suggested use cases should be tested for concluding more intuitive associations to the information. Also, for the visibility of shadow states, increasing the size of the lamp was suggested by the participants. In the light of this information, as future work, we plan to focus on a few of the suggested use cases (i.e. bedside lamp for environmental information) and iterate our concept and conduct in-situ evaluations.

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