Shadows as Ambient Displays - A Design Space

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Abstract. In this paper, we present a design space for using shadows in interactive systems. The main elements of the design space are optical properties, dynamicity, reality, temporality, and projection surface. The use and applicability of the design space are evaluated through three concept designs. The paper contributes a systematic approach to designing interactive systems with shadows, adding to the prior art focused on case studies.

Keywords: Shadows · design space · ambient displays · user experience

1 Introduction

Shadows are an integral part of our physical world and follow us everywhere. They are so familiar parts of life, that often we hardly notice their existence. Shadows are our silent companions, which cast an authentic, yet modified representation of the physical objects. Shadows offer interesting design opportunities as ambient displays. Ambient displays have been defined to locate at the periphery of the user's attention and present non-critical information in abstract and aesthetic ways [17]. Designing with shadows appears in various domains, examples illustrated in Fig. 1. Architectural pieces and physical products can take an advantage of shadows as a natural phenomenon, and utilize shadows as part of the aesthetics or functional design. Art has long explored the visual effects and illusions with shadows, from shadow puppet theatre to paintings and statues. Also, human-computer interaction and user interface design have integrated shadows as part of interactive systems. Today, also a growing domain of digital entertainment, for instance, video games, design visual effects with virtual light and shadows.

In this paper, we focus on the idea of using shadows as part of an interactive system's design. Interactive shadows have been used in performative arts, and there is a long history of utilizing them as part of the performance in dance, theatre, or other shows [4]. Interactive systems with shadow display concepts as part of the design have also been demonstrated in human-computer interaction (HCI) research. Interactive shadow displays have been studied in HCI research

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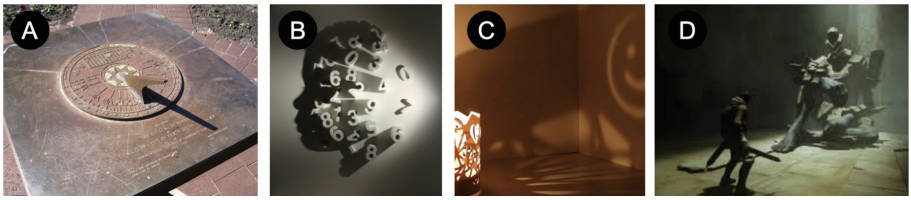

Fig. 1. Example domains where designing with shadows takes place. A) Sundial in Supreme Court Gardens, Perth, Australia. B) 0 to 9, Kumi Yamashita http://kumiyamashita.com/light-shadow C) Candle shadow display, Lappalainen et al. [16] D) Chronos, before the ashes. Gunfire Games http://gunfiregames.com/chronos-bta

with systems including candles [16] and lamps [13,22] as the light source, or with different physical objects such as plants [2] or people [24], or interacting with a mobile projector phone [3].

In this paper, we present a design space for using shadows as ambient displays, and expand the work presented in [23]. The design space is evaluated with a design exercise, where three concept designs using shadow metaphor in the ambient display design were used. The work extends the prior research on the topic and provides a more systematic approach to shadow display design than the case studies presented in prior art [2,13,22,24]. Our work contributes to the domain of interactive system and user interface (UI) design and supports designers working with the theme.

2 Related Work

2.1 Using Shadows in Visual Media

Shadows' application areas are abundant: In addition to philosophy in different fine arts and applied arts disciplines, shadows appear as an integral part of cultural artifacts. In the early 1920s shadows were used to achieve a narrative effect in intuitive filmmaking. In the cult German expressionist film Nosferatu, Eine Symphonie Des Grauens (1922), Shadows were applied with a specific intent to symbolize the relationship between light and dark. Furthermore, the shadow as a metaphor in cinematography was employed as a means of revealing the narrative intention between the filmmaker and the audience [6]. F.W. Murnau was a visionary film director of the silent era. He employed shadows and dreadful images with myriad variations of negative display techniques to leave an uncanny and eerie impression on the audience. Another seminal example of the use of shadows in the motion picture was Robert Wiene's The Cabinet of Dr. Caligari (1920), shadows were utilized to give a nightmarish quality to the narrative and to portray a quasi-surrealistic view of the sharp-angled geometric bizarre scenery [25]. Similarly, in the animated fantasy-adventure film, the Boy Who Wouldn't Grow Up (1953), produced by Walt Disney Studios as an interpretation of J.M. Barrie's Peter Pan, the artificial shadow of the character invites interplay with itself [27].

2.2 Shadows in Interactive Systems

The prior art has, through empirical studies, reported several different factors, which can affect the user experience with shadow displays. User experience (UX) has been defined primarily as a subjective experience, a feeling of good and bad when interacting with a product, and it consists of both hedonic and utilitarian aspects [8]. Shadows, either real shadows of physical objects or artificially created presentations mimicking shadows, have been presented in several concept designs in HCI. Authentic shadows have been used with light sources that employ dynamic parts to block the light. Casted shadows presenting different smileys have been used to convey messages with a motorized candle stand [7], and a lamp with dynamic screen shading the light has been used to illustrate a nighttime story for children [13]. Here, the aesthetic and unobtrusive appearance of the display has been found as a strength of the approach.

In addition, artificially created shadows have been used as ambient information displays. Colley et al. presented a concept where an indoor plant, placed on a desk next to a wall, was connected with a back-projected shadow image, making an illusion of the plant's real shadow. The shape of the shadow was then manipulated according to a (simulated) external information source, e.g. to grow flowers or spikes [2]. A similar technical setup was later used with artificial human shadows in a simulated cafeteria setting [24]. The user study revealed that with human shadows, the mirroring effect could be harnessed for guiding a user to action, as a moving shadow created in participants an urge to follow its moves. The synchronized timing and a gradual and slow enough morphing were also found to affect the user experience positively. It was deemed that it was important to maintain the illusion of a real shadow in the visual design of shadow displays.

In the following, we systematically wish to analyze, what are the elements the designer can manipulate when creating shadow displays.

3 Design Space

In this section, we draft the design space for using shadow as an ambient display, Fig. 2, and give examples of each aspect.

Optical Properties. In the context of its use as a design element, the main characteristics of the shadow are its unique optical properties. Shadows in the physical world are affected by optical properties, such as *transparency, color,* and *optical focus.* The specific shades of colors can be associated with the type of information, urgency, or intensity. Besides that, the color could create a coherency with the change of atmosphere in the physical space depending on the time of day.

In previous work, the notions of light and shadow, both literally and metaphorically, were used as a medium for ambient information display at the periphery of human attention [9]. For instance, Ishii et al.have developed *ambientROOM* [10] as a platform for peripheral awareness of bits supporting the

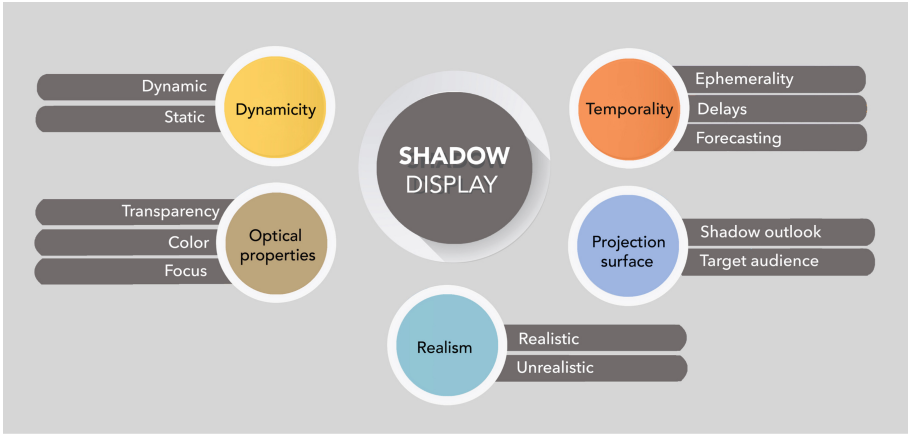

Fig. 2. The elements of the design space for shadow displays.

expression of digital information through ambient light, sound, airflow, and physical motion. The metaphor of light, shadow, and optics are compelling elements for interfaces enclosing virtual and physical space [9]. One particular display that utilizes the shadow to convey information is Wisneski et al.'s *Water Ripples* [32] provides ambient information about the physical activities of others through riffling shadows on the ceiling of ambientROOM. Also, shadow as a design element has so far been used in a variety of interactive art installations [19,20,26] Obushi and Koshimo's' 'Temari and Shadow' [20], an interactive digital installation utilizes natural shadows cast by people to enable embodied interaction. The work focuses on the three characteristics of natural shadow: "its effects of generating a sense of ownership, ease of manipulation, and its ability to express one's thoughts".

The transparency, or the opacity, of the shadow, is determined by how well the object blocks the light. If the light source is colored, e.g., yellow light, the light area surrounding the shadow is yellow. If there are artificial shadow silhouettes created with projected images, they can be colorful instead of black. Minomo et al. utilize colorful patterns, animations, textual information, photos, and live videos to make shadows colorful more naturally [18].

Dynamicity. Another aspect of the design space is the choice between the dynamic and static representation of shadow. The majority of works using shadow and light utilize its dynamicity, particularly those related to embodied interaction with the physical objects and space e.g. [1,11,31]. While a dynamic change in shadow can provide information about an ongoing process, a static interpretation can be associated with instant events. The dynamic representation of information might include a stage of the process or abrupt indications of a specific event. Choice of expression is one of the challenges of design space, and each of and depends on the type of information or notification to be conveyed. There may be some design approach that is more suitable than others. The shad-

ows are in constant flux, giving us subtle information about the environment, such as the time of day or the weather. The dynamic and static modes of artificial shadows can simulate human-nature interaction in public and private spaces. In addition to the optical qualities, the dynamicity of shadow also provides interesting viewpoints for the design of ambient displays. Realism Perception of shadow can differ according to a person's visual experiences. The shadows created artificially might not always give a realistic look. Perhaps one of the most compelling aspects of the artificial shadow metaphor is its consistency with real objects. The distorted sense of reality, which makes it difficult for users to perceive the object, is one of the optical constraints encountered in ambient display design.

Temporality. Another consideration when thinking about the design is to understand the temporality of the display. Visualization of artificial shadows can have temporal elements that change with time. *Ephemerality* is a state of the temporary existence of things only for a short period of time [5]. It is an important part of our experiences with our surroundings. Nature is filled with unique, expressive examples of ephemeral materials. Most of these ephemeral materials are perceived as poetic [5] due to their meaningful, expressive nature. Kuribayashi and Wakita presented PlantDisplay [15] as an example of an ambient display that utilizes a houseplant and allows implicit information with an ephemeral user interface. Especially in art, we often encounter works with ephemeral features. An example is Yves Klein's "Aerostatics Sculpture" composed of a thousand and one blue balloons into the sky [28]. Studies on the integration of ephemerality phenomenon in the design of ambient displays can open the door to different experiences and perspectives in human-computer interaction. Transient presentation of information might be one way to cope with the excess flood of information in all parts of our lives. To address this problem, research has developed calm computing [29], peripheral displays, [30] and ambient media [32].

Projection Surface. The surface where a shadow is cast primarily affects two aspects, the *outlook of the shadow*, and its *visibility*, which is important if we think to whom, or to which audience, the shadow display is targeted. Shadows are cast within an architectural space e.g. walls, doors, windows, desktops, floors, ceilings, might influence provide different functionality of usability. The shadow that is displayed on the surface of the water or onto a rough stone paving might provide different aesthetic modalities and modes of interaction. Shadow s a natural phenomenon that participants inherently grasp the interface and claim they "feel" the projected images as an extension of their body [26] Similarly, the Fragment Shadow [14] system enables the generation of visually transformed optical shadows in a calibrated projection space with a large screen surface. Jaynes et al., [12] introduced a technique that can be used to remove the appearance of shadows in front projection displays. The system detects and corrects transient shadows in multi-projector displays. Of related interest are works exploring display techniques and consistency problems such as ambient lighting, both being defining aspects of shadow.

4 Evaluation

To support our conceptual framework, in the following, we present the analysis of three interactive shadow design concepts against our design space.

4.1 Concepts

Three groups of university design students (n = 11 in total, 4 male and 7 female) were given a task to create an interactive concept utilizing a shadow display, and then reflect their designs against the design space framework. Three concepts, Tea Kettle, Smart Basket, and Melting Table were created Fig. 3. In Tea Kettle, the status of the kettle is cast on the wall next to it. With the Smart Basket concept, a shopping basket casts a large shadow on the floor, making the user aware of keeping a safe distance from other, as recommended during the Covid-19 pandemic. In the Melting Table concept, artificial shadows, which are created on a restaurant table, start slowly changing their form, creating a visual effect of a melting table. The concept designs are analyzed against the design space framework in Fig. 4.

Fig. 3. The concept designs using shadow displays, resulting from the student design task: an information display for a kettle, a shopping basket shadow to support social distancing measures, and a dining table with visual effects.

4.2 The Use of Design Space Framework

The analysis of the three shadow design space examples reveals that diverse solutions and approaches are used for similar purposes. In all cases, the participants, i.e. the designers of the three concepts, were able to articulate where they had used each design space dimension, and what kind of design decisions were made with respect to these. As the results show, while creating the design environment, a relationship has been established between physical space, tangible objects, and display. It is seen that these three elements are factors that affect each other in the design decision.

While color is not used in all three shadow designs created, considering that it can be distracting and will not contribute to the concept, and transparency is not sought, the optical property of focus plays an important role when the implicit display of information. However, transparency is used to make the display more

SHADOW DESIGN SPACE	Tea Kettle	Smart Basket	Melting Table
Concept description and connection with a tangible object	*"Tea Kettle"* is an ambient display concept using the shadows to display water temperature information and how much water is required for brewing different kinds of tea.	*"Smart Basket"* is a shopping basket that reflects a shadow around its carrier in order to determine safe space between people.	*"Melting Table"* is a concept designed to create awareness for climate change using melting shadows.
Optical properties: Transparency, Color, Focus	• Not too transparent. • Shadow needs to be focused so it shows the information in detail. • Shadow is black since numbers and icons are used.	• The transparency needs to be adjustable according to the store's lights and brightness. • Different colors should be examined more.	Transparency plays an important role when it is aimed to make shadows look more realistic, while color was not used since it can be distracting.
Dynamicity: Dynamic / Static	The shadow is dynamic.	The shadow is dynamic. It reacts to other shadows and indicates that the customer is too close.	Shadows are static they become gradually dynamic.
Realism: Realistic / Unrealistic	The shadows are unrealistic since there are no actual physical objects that cast shadow.	Shadows are manipulated. They are bigger than usual, they move and have different shapes.	First, shadows are realistic, and then slowly change to unrealistic with the illusion of melting.
Temporality: Ephemerality, Delays, Forecasting	The shadow stays until the kettle is turned on. There is no delay, and the shadow appears right away when the kettle is turned on.	The shadow appears when the user flips up and down the shopping basket handle. Shadow follows the basket and it can forecast confronts.	Shadows that melt away if the objects on the table are touched.
Projection surface: Shadow outlook, Target audience	Ambient shadows cast on the kitchen wall since the tea kettle is a kitchen appliance.	The shadow is cast on the floor. The color of the floor is the most essential aspect to take into consideration when designing the personalized shadows for different stores.	The surface is an active part of the concept. When the table is active the table itself emits some light and shadow to produce the melting shadow effect.

Fig. 4. Shadow concept analysis against the design space.

realistic and understandable. On the other hand, as seen in the framework, dynamic shadows are used in all three shadow designs due to the gradual change of information at different stages. The focus is strongly emphasized so that the information can be understood easily, as in the tea kettle concept, where the information includes numbers and icons, As specified in the dynamicity property of the shadows, since the shadow display consists of constantly changing shadow information such as different numbers, thus, the form of the shadow is dynamic. In the Realism section, unrealistic shadows are used both in Tea Kettle, where no object is associated with the shadow and in Melting Table, where the target is to create a visual illusion. The surface where the shadow is cast supports public visibility of the shadow display.

5 Discussion

In this paper, we have described properties and other factors which we considered creating the design space of shadows. Our design space for shadow as an ambient information display aims to describe broad application areas for the shadow as a design element that can provide interesting opportunities and experience-rich application areas. The aesthetic, semiotic, and functional qualities of shadow displays support their use in ambient design for information delivery. The analysis of the three concept designs against the design space shows, that the framework can be used to systematically analyze the design decisions and to evaluate different concepts.

Pousman and Stasko have defined four design dimensions for ambient information systems: information capacity, notification level, representational fidelity, and aesthetic emphasis [21]. This offers an interesting framework for future studies. Based on our experiences so far, the strengths of shadow displays lie in unobtrusive, yet dynamic notification level, and in aesthetics. User experience with shadow display systems is influenced by the temporal aspects of the shadow movements [24], the movement dynamics [24], and the level of realism in the shape of the shadow [2,24]. As future work, we aim to gain more insight into quantifying the UX with shadow displays through a systematic empirical study.

6 Conclusion

We have presented a design space for the properties of shadows as ambient displays. The main elements of the design space for shadows are 1) the optical properties, including transparency, focus, and color, 2) dynamicity, 3) reality, 4) temporality, including ephemerality, delays, and forecasting with the shadow's movements, and 5) projection surface, which affects to the outlook of the shadow, but also who the shadow display is targeted for. Our work offers a systematic approach to designing and evaluating the properties of shadows in interactive systems.

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References

1. Chikamori, M., Kunoh, K.: Kage. In: ACM SIGGRAPH 98 Electronic Art and Animation catalog, p. 14 (1998)
2. Colley, A., Raudanjoki, Ö., Mikkonen, K., Häkkilä, J.: Plant shadow morphing as a peripheral display. In: Proceedings of the 18th International Conference on Mobile and Ubiquitous Multimedia, pp. 1–5 (2019)
3. Cowan, L.G., Li, K.A.: ShadowPuppets: supporting collocated interaction with mobile projector phones using hand shadows. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, pp. 2707–2716. CHI 2011, ACM, New York, NY, USA (2011). https://doi.org/10.1145/1978942.1979340
4. Currell, D.: Shadow Puppets and Shadow Play. Crowood, Marlborough (2015)
5. Döring, T., Sylvester, A., Schmidt, A.: A design space for ephemeral user interfaces. In: Proceedings of the 7th International Conference on Tangible, Embedded and Embodied Interaction, pp. 75–82 (2013)
6. Franklin, J.C.: Metamorphosis of a metaphor: the shadow in early German cinema. Ger. Q. **53**(2), 176–188 (1980)
7. Häkkilä, J., Lappalainen, T., Koskinen, S.: In the candle light: pervasive display concept for emotional communication. In: Proceedings of the 5th ACM International Symposium on Pervasive Displays, pp. 161–167. PerDis 2016, ACM, New York, NY, USA (2016). https://doi.org/10.1145/2914920.2915009

8. Hassenzahl, M.: User experience (UX) towards an experiential perspective on product quality. In: Proceedings of the 20th Conference on l'Interaction Homme-Machine, pp. 11–15 (2008)
9. Ishii, H., Ullmer, B.: Tangible bits: towards seamless interfaces between people, bits and atoms. In: Proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems, pp. 234–241 (1997)
10. Ishii, H., et al.: ambientROOM: integrating ambient media with architectural space. In: CHI 98 Conference Summary on Human Factors in Computing Systems, pp. 173–174 (1998)
11. Ishii, H., Wisneski, C., Orbanes, J., Chun, B., Paradiso, J.: PingPongPlus: design of an athletic-tangible interface for computer-supported cooperative play. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, pp. 394–401 (1999)
12. Jaynes, C., Webb, S., Steele, R.M., Brown, M., Seales, W.B.: Dynamic shadow removal from front projection displays. In: Proceedings Visualization, 2001. VIS2001, pp. 175–555. IEEE (2001)
13. Jensen, W., Löchtefeld, M., Knoche, H.: ShadowLamp: an ambient display with controllable shadow projection using electrochromic materials. In: Extended Abstracts of the 2019 CHI Conference on Human Factors in Computing Systems, p. LBW1510. ACM (2019)
14. Kasahara, S., Higa, S., Komori, A.: Fragment shadow: generating fragmented shadows with multi-projectors geometry and color calibration. In: ACM SIGGRAPH 2019 Studio, pp. 1–2 (2019)
15. Kuribayashi, S., Wakita, A.: PlantDisplay: turning houseplants into ambient display. In: Proceedings of the 2006 ACM SIGCHI International Conference on Advances in Computer Entertainment Technology, pp. 40-es (2006)
16. Lappalainen, T., Colley, A., Beekhuyzen, J., Häkkilä, J.: Candle shadow display for ambient communication delivery. In: Proceedings of the 2016 ACM Conference Companion Publication on Designing Interactive Systems, pp. 13–16 (2016)
17. Mankoff, J., Dey, A.K., Hsieh, G., Kientz, J., Lederer, S., Ames, M.: Heuristic evaluation of ambient displays. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, pp. 169–176. CHI 2003, ACM, New York, NY, USA (2003). https://doi.org/10.1145/642611.642642
18. Minomo, Y., Kakehi, Y., Iida, M.: Transforming your shadow into colorful visual media: multi-projection of complementary colors. In: Proceedings of the 2005 ACM SIGCHI International Conference on Advances in Computer Entertainment Technology, pp. 61–68 (2005)
19. Mitra, N.J., Pauly, M.: Shadow art. ACM Trans. Graph. **28**(CONF), 156–1 (2009)
20. Obushi, N., Koshino, M.: Temari and shadow: an interactive installation combining virtual handicraft and real shadow. In: Proceedings of the Virtual Reality International Conference-Laval Virtual, pp. 1–4 (2018)
21. Pousman, Z., Stasko, J.: A taxonomy of ambient information systems: four patterns of design. In: Proceedings of the Working Conference on Advanced Visual Interfaces, pp. 67–74 (2006)
22. Raudanjoki, Ö., Genç, Ç., Hurtig, K., Häkkilä, J.: ShadowSparrow: an ambient display for information visualization and notification. In: 19th International Conference on Mobile and Ubiquitous Multimedia, pp. 351–353 (2020)
23. Raudanjoki, Ö., Häkkilä, J.: Towards a design space for shadows as ambient displays. In: Ardito, C., et al. (eds.) INTERACT 2021. LNCS, vol. 12936, pp. 509–512. Springer, Cham (2021). https://doi.org/10.1007/978-3-030-85607-6_68

24. Raudanjoki, Ö., Häkkilä, J., Hurtig, K., Colley, A.: Perceptions of human shadow manipulation as an ambient display. In: Proceedings of the 9TH ACM International Symposium on Pervasive Displays, pp. 71–77 (2020)
25. Robinson, D.: Das Cabinet des Dr. Caligari. Bloomsbury Publishing, London (2013)
26. Simpson, Z.B.: Shadow garden. In: Proceedings of the 29th International Conference on Computer Graphics and Interactive Techniques. Electronic Art and Animation Catalog, pp. 84–85 (2002)
27. Skinner, J.: James M. Barrie or the boy who wouldn't grow up. Am. Imago **14**(2), 111–141 (1957)
28. Solnit, R.: Yves klein and the blue of distance. New Engl. Rev. (1990-) **26**(2), 176–182 (2005)
29. Weiser, M.: The computer for the 21st century. Sci. Am. **265**(3), 94–105 (1991)
30. Weiser, M., Brown, J.S.: Designing calm technology. PowerGrid J. **1**(1), 75–85 (1996)
31. White, T., Small, D.: An interactive poetic garden. In: CHI 98 Conference Summary on Human Factors in Computing Systems, pp. 335–336 (1998)
32. Wisneski, C., et al.: Ambient Displays: turning architectural space into an interface between people and digital information. In: Streitz, N.A., Konomi, S., Burkhardt, H.-J. (eds.) CoBuild 1998. LNCS, vol. 1370, pp. 22–32. Springer, Heidelberg (1998). https://doi.org/10.1007/3-540-69706-3_4