Shadow Display Design Concepts for AI Enhanced Environments

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Abstract. In this paper, we focus on the idea of using artificial shadows as information displays. Through scenarios, co-design methods, and low-fi prototyping, we assess and create different scenarios to chart people's preferences in designing shadow displays. We report on two user studies, which reveal aesthetics, experiental aspects, unobtrusiveness, and ambiguity as key strengths of shadow displays. Our work contributes to the research knowledge in applying co-design methods to create user interfaces for artificial intelligence (AI) enhanced environments.

Keywords: co-design methods · shadows · pervasive displays · explainable AI · user studies · User Experience · design

1 Introduction

Intelligent environments are already present in our everyday lives, and often our surroundings are equipped with technology—displays, home electronics, smart objects, and the different gadgets we carry with us. Whereas today we live in a world with mobile devices and the internet of things, and emerging technologies will enable scenarios where technology is increasingly integrated into our environment. In visions of future technologies, *calm computing* has been proposed as a desired direction for future development [34]. Here, the key idea is to integrate the technology in an unobtrusive way and move it to the periphery of the user's attention. When compared to the current visible omnipresence of technology, e.g. screens placed in urban environments [22] or mobile phone use causing distraction and addiction [14], this requires a paradigm shift from obtrusive to unobtrusive technology. With this in mind, in our research, we are interested in exploring the future design possibilities of unobtrusive technology, where the technology is embedded in our everyday surroundings.

Artificial intelligence (AI) is an emerging technology that will have an impact on many application sectors. However, the possibilities of AI, and how it will appear and be understood by people, are still quite unclear in practice. Indeed,

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the current development trends of AI solutions have been criticized for their lack of transparency and interpretability [11]. It is evident that more research on explainable AI (XAI) and human perceptions and preferences are needed. Here, low-fidelity prototyping and participatory design methods offer an approach, where XAI scenarios can be explored without requiring actual technical implementation.

In this paper, we present the concept of utilizing shadows as a metaphor and interface for explainable AI. Shadows are a familiar and natural part of our physical world, and thus offer possibilities for use in unobtrusive design. By manipulating and creating artificial shadows, they can be used as ambient information displays [9,32]. We present two studies that complement each other. The initial study focused on designer-created scenarios of augmented shadows as information displays, which were assessed by 77 participants. The second study, organized as two co-design workshop sessions, included 7 participants. We apply different methods utilizing a self-expression template and low-fidelity materials, such as paper cut-outs, dolls, and everyday objects to visualize and brainstorm around the rather technical concepts of AI-enhanced environments and shadow displays.

Creating shadow displays requires quite complex technological set-ups, combining, e.g., context awareness in interpreting the environment and user's actions and intentions, camera-based detection of objects and people, and image processing and projection technologies to create realistic artificial shadows. Our research provides insight both into people's perceptions of using artificial shadows as interactive displays, and new hands-on knowledge on how co-design and low-fi prototyping methods can be applied to AI design research.

2 Related Work

2.1 Ambient and Shadow Displays

Mankoff et al. define ambient displays as *"abstract and aesthetic peripheral displays portraying non-critical information on the periphery of a user's attention"* [25]. Placed at the outskirts of the user's attention, ambient displays are a promising information presentation technique to avoid overloading the user with distractions and information. Already early works on peripheral displays started looking at aesthetically interesting designs and how to convey information with them, both as graphical user interfaces [13] as well as physical objects [16]. Ambient displays have been demonstrated attached to the body through wearable computing or on-skin interfaces. For instance, the IdleStripes shirt informs an office worker that it is time to take a walking break by lighting fiber optic elements embedded in the shirt [15], and Tattio skin interfaces which use thermochromic elements to change the color of a temporary tattoo interface [21].

Shadows are a phenomenon that is visible everywhere in our surroundings without us consciously noticing them. Thus, manipulating shadows and creating artificial extensions resembling their authentic representation offers an interesting possibility for design. Shadow displays can be formed by altering the optical properties, dynamicity, reality, temporality, and projection surface [31]. In

a world where technology can be overwhelming, shadows offer a display possibility that is unobtrusive and ephemeral, meaning that the user interface can appear and disappear without leaving a trace [10]. Shadow displays have been used, e.g. in traditional shadow theater performances, and recently, applied in experimental aesthetic displays in interactive systems. These include, e.g. lamp shadow displays achieved with dynamic shades [20], and illusions of human shadows created with back-projection technology [32]. Raudanjoki et al.'s study [32] demonstrated how artificial, dynamic shadows can convey meanings and messages, for instance, signaling and guiding people. Shadows are used as part of the visual hierarchy in current UI design systems, such as Google's material design and Apple's iOS, to convey depth and support interaction[1].

2.2 Connecting Design and AI

Shadow display concepts require enabling technology, which can meet the demanding requirements of initiating, creating, and broadcasting artificial shadows. Artificial intelligence (AI) enhanced environments are expected to provide such settings. AI is now present, although usually not visibly, in a wide variety of people's everyday interactions. However, typically users have almost no understanding of the reasoning behind decisions made by AI systems. The field of Explainable AI (XAI) [26] aims to provide users with an understanding of the reasons behind the AI system's decisions. This increases users' trust in the system [30], e.g. users can see that the system is operating fairly and providing correct outputs.

One commonly researched approach to XAI is to develop a simplified human-understandable surrogate of the AI model, that users can reference when evaluating the system's outputs [24]. In a recent work, Chromik and Butz [8] present guidelines for this approach. Other approaches include providing a 'what if?' interface, such that users can experiment with adjusting input parameters and see their effect on the system's output [18], and thus gain an understanding of how the system works. Hendricks et al. [17] developed a solution that produced textual sentences to explain (or rather justify) the decisions of an AI image classifier. Such approaches increase the cognitive load on the user when interfacing with the system. In our work, were are interested to explore the potential for ambient visualization elements to convey XAI information to the user, and to utilize AI-enhanced environments for creating shadow displays.

2.3 Positioning of Our Work

In this paper, we extend the current work on shadow display design exploration and explore the possibilities to use shadow displays as part of an intelligent system. Through scenarios and co-design methodology, we chart people's ideas and perceptions related to the concept of shadow displays in different scenarios and contexts. Our findings contribute to the user-centric understanding of how

[1] https://material.io/design/environment/light-shadows.html.

intelligent systems could utilize shadows as part of smart environments, and pave the way toward one possible design direction for explainable AI.

3 Methodological Approach

In our research, we used scenarios, co-design, and low-fi prototyping as the methodological approaches.

Scenarios, i.e. staged situations illustrating or describing a potential use of technology, have been found useful for inspiring users and designers toward creative design solutions [3]. They can be used to provoke thoughts, and to assess the positive and negative aspects of technology use [3]. The granularity of scenarios can vary [35], and they are at the same time concrete but still flexible [7], which makes them a good tool to adapt to different kinds of design contexts. Wolf et al. have presented how a scenario-based design approach can be a useful tool for exploring XAI, as scenarios leverage the possible use of a technology that is still in the early stages of development [35].

Co-design methods allow designers and non-designers to design together [33]. To scaffold and stage collaborative design activities, different kinds of material artifacts have been used over the years [4]. Traditional co-design workshops have relied on mundane materials, such as paper and cardboard, as they are easily molded by non-designers allowing them to express themselves in a shared design space with designers [2,12] or to expose the tension between stakeholders and trigger participants to productive discussions [5,27]. The context of the design should define the suitable lo-fi materials, such as a co-design session for a smart handbag, which utilized different kinds of fabrics, leather, and printable electronics [29]. These mundane materials are often also accompanied by less modifiable material artifacts, such as bottles or plastic toys, as props that prompt participants' imagination [28] or support the narrative of the co-design workshop [6,19].

In co-design activities, the designer's role is to facilitate the activities and provide their expertise on the existing, new, and emerging technologies, and to give a grounding in production processes and business contexts [33]. This is especially important with novel and emerging interactive technologies, for non-designer participants to succeed in creating novel, but feasible, ideas. The co-design workshop process, selection of the separate design activities, as well as their relative order also impacts the design outcomes. With novel interactive technologies, prior research has used existing designs as a primer for the co-design activities [29] with the idea of expanding participants' views beyond the most cliché ideas.

4 Study I - Assessing Scenarios

4.1 Set-Up

In the first part of our research, we focused on public and private use cases of artificial human shadows. We created four different scenarios involving manipulated human shadows as information-carrying elements in physical spaces.

Fig. 1. Scenarios with augmented shadows as information displays.

In the first scenario, Fig. 1, we used a human picture in a home setting with a shadow cast on the wall drinking a bottle of water. For the second scenario, we designed an office space where the shadow of the user's hand moves over the work desk informing the user about certain tasks such as reminding of daily water intake or taking notes for an upcoming event. Whereas the first two scenarios took place in private environments, scenarios 3 and 4 focused on public areas. In the third scenario, a presenter is giving a presentation in a public environment with a shadow on the wall making a pointing gesture to support the presentation.

To evaluate the shadow display concepts, a survey-based study was organized. In each scenario, participants were asked to assess the concepts and highlight their favorite and least favorite attributes. To evaluate the scenarios and their perceived strengths and concerns, we recruited 77 participants from different design backgrounds from the University of Lapland, Finland. They participated in the study in groups of 1–3 people, resulting in a total of 34 responses for the analysis phase. We first explained the scenarios verbally and then provided a template presenting each scenario, including open-ended questions, and selection of most and least favorite scenarios.

4.2 Results of Study I

The analysis of the research reveals that the majority of the participants preferred the exhibition scenario (scenario 4), whilst the least liked was the home concept (scenario 1), Fig. 2.

Scenario 1. Altogether, scenario 1, which showed a person working from home, was the least favorite of the participants. Participants' negative comments focused on challenges with noticeability and interpretation, e.g. "The shadow on

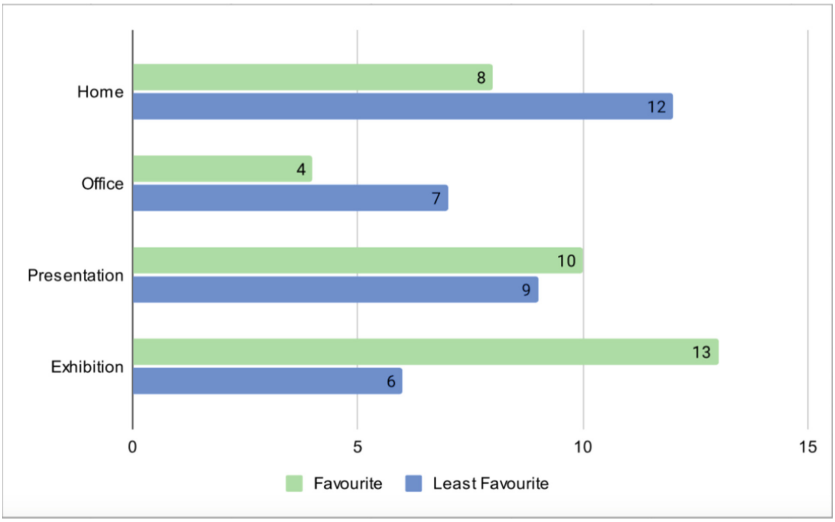

Fig. 2. The most and least liked scenarios.

the side seems a little scary and barely noticeable. In my mind, in general, the 'shadow alarm' requires a little [time] to get used to" (P9). The ease of noticing the shadow was questioned, e.g. "because I don't think I would notice the shadow while working, as it would be on the side and not bright or clear" (P17). The positive comments were related to ambiguity, e.g. "shadow tells many stories depending on the viewer" (P18), and on customizing one's surroundings in a personal way. On the other hand, some people felt the shadow display was simple and clear, e.g. "message is somewhat obvious and conveys from the very simple silhouette" (P10).

Scenario 2. Similarly to scenario 1, the second scenario, an office setting with a person working and the shadow of his hand on the table, created an interpretation challenge: "I don't understand what it wants to say" (P8). Also, concerns about noticing the shadow and visual clutter arose: "Scenario 2 seems most difficult because at the office there are already lots of distractions, so this could make it more confusing" (P26).

Scenario 3. Showing a presenter, was considered by nearly all participants to be practical, e.g. "The shadow in the presentation situation is my favorite because it could enormously helpful in a presentation" (P14). Several participants noted the concept's potential benefits, e.g. " the presenter doesn't need to worry about anything else than talking. The shadow makes the demonstrations. This scenario is the most useful from a utilitarian point of view" (P25), and "it makes the presentation more diverse" (P22).

Scenario 4. There was generally positive conversation about the exhibition scenario, where the shadow guides a person's navigation. It was considered both useful and enjoyable, "This is my favorite scenario because it helps with navigating in an unknown space. It can also bring the space to life and be art itself" (P13). Also, other comments combined utilitarian and experiental aspects: " it can be a good solution and a personal guide for example for tourists and other people who need help. It can be once-in-a-lifetime memory" (P26), and "scenario 4 was my favorite because I like museums, and it would help my museum experiences" (P15).

5 Study II - Co-design Workshop

5.1 Study Set-Up

The second study was constructed around a co-design workshop. The research methodology was based on human-centered and collaborative design-oriented processes consisting of two consecutive, approximately two-hour sessions with a total of seven participants. The first session had five participants (2 female and 3 male), and the second session had two participants (1 female, and 1 male). The participants were design students and staff from the department of industrial design at the University of Lapland, Finland. The focus of the study was to examine people's preferences for designing shadow displays in private and multi-person settings through three tasks. These tasks consisted of, 1) scenario assessment with positive and negative aspects of shadow displays, 2) expression of participants' own personal and public shadow concept ideas by drawing and writing on a self-expression template, and 3) co-design and creation of low-fidelity physical prototypes.

A total of four different scenarios were created, two being an object and a person in a private venue, and the other two being the representation of an object and a human in the public space. The images used to visualize the scenarios were compiled from an online stock image provider and the researcher's own archive.

5.2 Study Tasks

For the first task, four images of concept designs of shadow displays were placed on the wall. Two different colors of post-it notes, pink and green, were provided to participants, and they were asked to give insights about the positive (green notes) and negative (pink notes) aspects of each concept (Fig. 3). After that, participants were asked to discuss the perceived positive and negative qualities of each scenario, and they were given time to evaluate each concept from different angles. The illustrations used in Task 1 included:

- *private space, object shadow*: coffee mug shadow functioning as a reminder.
- *private space, human shadow*: washing hands with the shadow guiding for the soap use.

Fig. 3. Assessment of positive and negative properties of concepts in Task 1.

- *public space, object shadow*: manipulated shadow of a lamp in a library, with subtle cues of a bus approaching and leaving.
- *public space, human shadow*: library, with a visitor's manipulated shadow that gives guidance for finding a book.

In Task 2, we introduced self-expression templates to investigate shadows' practical use in two different design spaces. Participants were asked to reflect on their ideas on the human figure: How they would like to use ambient shadow displays in which location and for what purpose. To gain deeper reflections on the displays, we allowed participants to utilize different ideation methods including drawing, doodling, and writing, to express their concepts. The self-expression template consisted of a human figure in the bottom right, and a group of human figures that represent people in public space, in the top left (Fig. 4).

Task 3 focused mainly on hands-on concept design. As we wished to visualize shadow displays in the scenario, we decided to utilize co-creation and brainstorming scenarios. The facilitators gave the participants a variety of different objects, ranging from kitchen appliances to children's toys. Participants were asked to choose an object and design their shadow display concept. To create the cutout shadow forms participants were distributed black cardboard, Fig. 5. The majority of the participants (5/7) completed the task individually. The time taken for the task varied between 15 and 20 min.

At the beginning of the session, participants completed a consent form and a short background questionnaire. At the end of the session, participants completed a short questionnaire to provide an assessment of the likeability of the shadow display concept and personal reflections regarding the object, location,

Fig. 4. Task 1 in action.

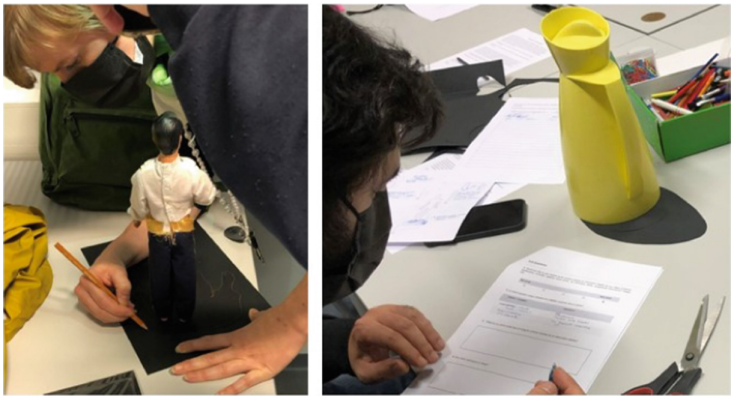

Fig. 5. Creating scenarios with objects and artificial shadows in the co-design session: shadow for a human (left) and coffee thermos jug (right).

and context of shadow displays. The study was facilitated by one researcher while another researcher was responsible for observing and documenting the process using notes, photos, and video recordings, which were later transcribed for analysis.

5.3 Participants

We recruited seven participants (3 female) aged 21–29 (3 persons) and 33–36 (4 persons), who were students and staff at the university of Lapland, Finland, with design or technology backgrounds. A workshop moderator and an observer, who took notes and documented the studies, ran the workshop sessions. Both workshop sessions were video recorded for later analysis.

6 Findings of Study II

6.1 Assessing the Shadow Display Concepts

When assessing the shadow display concepts in public and private spaces, Fig. 3, overall, the participants found the unobtrusive communication concepts interesting and fun. For instance, a shadow of a coffee mug was generally interpreted as a pretty, unobtrusive decorative element: "Nice that it is ambient and not disturbing. Can be a pretty decorative shadow element." Reminder concepts using shadows were considered to be useful and unobtrusive in interior space: "This would be great since it's a reminder but not annoying like sounds, lights, etc...". The aesthetic qualities of the concept were also referred to: "Visually and conceptually fun, not distracting and as a piece of interior design". The opportunity to have a visual indicator instead of light and sound was found useful: "I think the basic idea of the lamp thing is really good... I think the best for this kind of shadow use because it is silent and non-disruptive and if you know what to look for it tells you something actual, valuable information" (P7). Using shadow as a guide to navigate in public spaces was generally considered useful.

As in Study I, there were also concerns regarding the noticeability: "Maybe hard to notice or interpret correctly". Again, also the challenge of interpretation was stated: "First you have to learn the meanings of different shadows". For instance, with the subtle cues used as reminders, it was commented that "I would definitely not understand the time I need, e.g. for the next bus". The visibility and location of the shadow were also highlighted as a design challenge. It was commented that the shadow needed to be attached to the actual object, and, for instance, the shadow guide concept would be hard to use if there were "multiple users and bystanders who might be in the way". Furthermore, some participants highlighted privacy concerns as the shadow was a publicly visible figure which might attract too much attention.

6.2 Generated Ideas

In the workshop, participants generated 14 ideas altogether. They ranged from reminder concepts to futuristic interaction ideas. Most of the idea descriptions were not elaborated in sufficient detail to explain all the necessary aspects but concentrated on giving a brief description using quite general terms. Although the created ideas and explanations reflected examples from the provided materials given in the first task, the ideas also included reflections from the participants' experiences, needs, and expectations.

Temporal Aspects. Analysis of the co-design workshop data revealed that many of the proposed concepts related somehow to temporal aspects in conveying information. Especially, the shadow displays were often used as a reminder in the participant-suggested concepts. Three of the participants suggested using a shadow display for the indication of time. This was verbalized as "shadows near windows growing darker when it's dark and you can't tell the time from outside,

to tell you it's time to sleep" (P1), and "A shadow that fills in and creeps up the wall as the day goes by. The shadow decreases when the night is coming, reminding you to relax and go to bed. A wake-up clock" (P7). Temporality was also highlighted when a shadow display was imagined to show "[...] how much of days tasks are done or how long till I can go home" (P3).

Relaxation and well-being related reminders and guidance were one of the most preferred themes, reflected by participants P2, P4, P5, and P7. Ideas such as "indicating to wear enough clothes." (P2), or "the shadow of the big plant covers my whole desk to remind me to take a break from working" (P4). Also, it was suggested that for a "reminder for exercise, a shadow moving crazily. [...] or a massage helper"(P5).

Warnings. Some participants suggested that shadows may be used as an interactive warning sign in the context of public use: "Walking in the evening, giving attention to passers-by so you don't get startled" (P1). In subsequent participants' comments, design ideas were put forward, which aimed to provide solutions to problems related to safety in public places: "The shadow reminds you if you're walking in the bike lane or vice versa" (P8). Another participant suggested creative applications that could be used as an interactive warning: "Scary or dangerous things can have monster shadows to warn children" (P7).

Social Aspects. There were also some comments related to navigation, such as guidance to a "coffee place nearby... 2 min walk" (P2). The participants also emphasized that the display information might be used to create playful interactions in social activities. As one participant explained, "at a party my shadow dances while I stand to get others' attention." (P4). Also, shadows could be used to create connections between people: "I would want to send and receive [shadow] emojis to my partner. A nice way to remind I miss them. Seeing them on the room wall"(P3).

Some participants suggested shadow displays to expand social interaction with their surroundings, whilst others to protect their personal space, e.g. to avoid social interaction in public places. " Having a personal shadow to show if I want to be alone or talk to people" (P3). Another participant highlighted both social aspects and privacy issues: "[I would use shadows for] storytelling for kids or adults. [...] Definitely no personal reminders in public since the shadow could be visible to others" (P5).

7 Discussion

7.1 The Design Potential of Shadow Displays

Throughout the studies, some central themes emerged. The experiental and aesthetic nature of shadow displays was emphasized in both studies, and many

comments revealed that. Even with concepts where utilitarian value and usefulness were appreciated, the feedback was often accompanied by comments related to experiencing or enjoying the shadow visualization. The potential for playful user experience and surprising elements in shadow display design have also been pointed out by earlier research [32]. As ambient displays often seek to be aesthetic, this matches well with the idea of shadow displays.

It was also evident that one central issue is the ambiguity of the shadow display. We speculate that the ambiguity of the visualization is both a strength and a weakness of the shadow display concept. The noticeability of the display and people's ability to interpret its information was questioned. However, on the other hand, the same characteristics provide the potential for design, e.g. in use cases where the shadows display secret or coded messages, visible in public but understood only by a certain person. This kind of encoded messaging has been introduced in prior art on ambient displays [23]. Shadows were also deemed unnoticeable and unobtrusive. Hence, they probably should not be used to convey critical information, but have the potential as an ambient information channel.

7.2 Aspects with AI Enhanced Environments

To realize the developed shadow display concepts a high-fidelity intelligent environment is needed. Realizing useful use cases with shadow displays requires context awareness [1], as the system needs to be aware of all the relevant aspects influencing creating a shadow display visualization. The ability to infer the user's needs and intentions is needed to provide the correct visualization at the right moment. Producing the output requires, e.g. camera-based environment mapping, machine learning techniques, and projection or other display techniques to create the artificial shadow presentations. This suggests AI would be a required enabling technology to create shadow displays in real environments. Whereas in this study AI is only considered as a background enabling technology, it is interesting and important to consider design aspects for such settings. We believe our research provides an interesting viewpoint for designers of AI-enhanced environments.

7.3 Methodological Notes

Our co-design workshop for shadow displays aimed to open user perceptions, needs, and requirements through a hands-on creative experience. The study provided insights into the aesthetic and functional qualities of shadow displays and how users perceive them in different architectural spaces. However, it is challenging to design for technology-centric future scenarios. In designing and brainstorming different applications, rapid prototyping of the concept ideas and user-centric design principles are often at the core of the design process. These may be difficult to match with the technology development capabilities and timeline. Hence, low-fidelity mock-ups, Wizard-of-Oz testing, role-playing, and imaginary devices are design techniques that can be applied.

7.4 Limitations

We acknowledge that our study is limited by the small sample sizes. However, as this is a preliminary study for co-designing ambient shadow displays for intelligent environments, we believe that our study can provide a useful basis for future studies. Multiple tasks and methods were used to make participants think from different angles and possibilities with the topic. To gain more reliable insights, user perceptions should be explored in a variety of real-life contexts over a longer period of time.

8 Conclusion

In this paper, we have presented our work on using shadows as information displays in intelligent environments. Two user studies assessing and ideating shadow display scenarios were organized. The findings highlight that shadow displays are ambient and provide an aesthetic and experiental way to convey information. Altogether, aesthetics, experiental aspects, unobtrusiveness, and ambiguity emerged as the key strengths of shadow displays. The key challenges arise from the facts that shadows were deemed hard to notice and interpret. Also, it should be acknowledged that shadows are publicly visible, which affects privacy as well as their visibility, due to surrounding clutter. Our research looks toward the future of designing for AI-enhanced environments, which can support the creation of shadow displays.

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