Exploring the Potential of Augmented Reality in Domestic Environments

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ABSTRACT

While Augmented Reality (AR) technologies are becoming increasingly available, our understanding of AR is primarily limited to controlled experiments which address use at work or for entertainment. Little is known about how it could enhance everyday interaction from a user's perspective. Personal use of AR at home may improve how users' interface with information on a daily basis. Through an online survey, we investigated attitudes towards domestic AR. We further explored the opportunities for AR at home in a technology probe. We first introduced the users to AR by offering an AR experience presented through mixed reality smart glasses. We then used a tailor-made tablet application to elicit photos illustrating how users imagine future AR experiences. Finally, we conducted semi-structured interviews based on elicited photos. Our results show that users are eager to benefit from on-demand information, assistance, enhanced sensory perception, and play offered by AR across many locations at home. We contribute insights for future AR systems designed for domestic environments.

CCS CONCEPTS

• **Human-centered computing** → **HCI design and evaluation methods**; **Empirical studies in HCI**; **Mixed / augmented reality**;

KEYWORDS

augmented reality; survey; technology probe; domestication

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1 INTRODUCTION

The vision of ubiquitous information access is still an actively researched challenge even though it began almost two decades ago [35]. Smartphones, smartwatches, and tablets are now omnipresent and used by the general population. Yet, these devices offer only minimal possibilities of embedding information in the environment. In contrast, envisioned Augmented Reality (AR) technology proposes exciting prospect of engaging directly with the lived environment and augmenting everyday spaces with digital artifacts. Augmented reality games like Pokémon Go have successfully enhanced social interaction and active learning [30]. Despite these appealing qualities, AR is yet to enter widespread use.

Historically, the development of interaction techniques and applications for AR was slowed by high equipment costs and technical complexity. However, recent technological advances, like powerful smartphones and continuous development of AR glasses, indicate that the widespread availability of AR technologies is a highly probable technical future. Consequently, understanding how AR can become part of everyday spaces and change everyday interactions with technology and the world emerges as a relevant question for Human-Computer Interaction (HCI). As AR-capable technologies are becoming more available to users, we must understand the design constraints and consequences of deploying AR systems in domestic environments.

Past research investigated specific usage scenarios for AR, e.g., in teaching or industry [12, 26, 32], and a significant body of research addressed interaction techniques for AR through controlled experiments [2, 6]. A recent review [8] found that application areas for AR were primarily tech-driven and determined by the controlled experiments researchers were

able to run. Further, most research efforts investigated work or entertainment scenarios, with less attention devoted to domestic use cases. Consequently, there is a need to elicit scenarios envisioned by potential users and explore the opportunities for developing AR for the home.

To explore this gap, we turned to the users to investigate their visions and attitudes towards AR. We first conducted an online survey and investigated user attitudes towards AR technology at home. Based on the answers, we built an initial understanding of potentially acceptable usage scenarios and desirable interaction techniques. This enabled us to identify concepts that could be explored further. Next, we conducted a 14-day technology probe with 13 participants in four households. Our probe consisted of an initial introduction session with the HoloLens, followed by 14 days of data gathering with a dedicated mobile application that simulated an AR device for photo elicitation. At the end of the study, each photo was discussed in a semi-structured interview. With this research, we can understand user position with regards to usage scenarios as well as constraints and limitations. We found that users were eager to experiment with AR and identify potentials for its usage. We identified five main themes that describe domestic AR in the gathered data: ASSISTANCE, ENHANCING PERCEPTION, SOCIAL ACTIVITY, DEVICE AUGMENTATION, and CONCERNS. Based on our results, we contribute recommendations for future research and design in AR for household environments.

The main contribution consists of two studies that address possibilities for domesticating AR: (1) an online survey with $n = 60$ participants and (2) a technology probe conducted in four households. Based on the analysis of the data collected in both studies, we contribute insights on expectations, constraints, and challenges for future wearable AR devices that aim to address interactions in home life.

The paper is structured as follows. First, we review related works that address AR technologies and technology probes in a domestic environment. We then describe the methodology of the survey and probe in detail, accompanied by the results of these studies. Finally, we discuss insights, challenges, and opportunities for AR applications for home environments.

2 RELATED WORK

Our work builds on past advances in AR and the development of technology probes as a research methodology. Here, we review research that motivated our study of domestication in AR and informed our choice of methodology.

Applications of Augmented Reality

AR is a combination of the virtual and real world, where virtual objects are superimposed in the surrounding environment in real time to enhance reality and user experience [1]. Past research explored extensively where and how AR could be applied to improve the user experience or task efficiency. Thomas et al. explored how AR can be used to create playful experiences [33]. They designed ARQuake; an outdoor mobile AR game. While the game was positively perceived by the users, many interaction issues specific to AR were revealed. These include effective item selection, tracking, and multi-person collaboration. AR has also been used for therapy, and studies showed that AR could be useful in other medical circumstances, such as treating phobias by reducing people's fear of insects or animals [21].

Education is another field of opportunity for AR. Lucklin et al. showed that AR systems could be used to motivate and engage children in learning activities [22]. AR learning experiences can also foster improved knowledge sharing [27] and make the unseen visible in physics lab courses [32]. Industrial applications have also been explored. Funk et al. showed that projected AR could contribute to efficiently training assembly line workers [12]. Further, Liu et al. showed that handheld AR devices with real-time feedback outperformed paper and picture instruction [20] in providing contextual training queues. The works listed above were included in a recent review of AR user studies by Dey et al. [8]. The review identified that past application areas for AR, which were subject to user studies were primarily professional environments or actions connected with entertainment. The review also highlighted that user knowledge in the AR field is primarily based on technology-driven within-subjects experimental research and more engagement with users in the field was required.

Our work is interestingly different from past efforts as it explores a frontier beyond the usual scope of AR applications — users at home. Further, instead of adapting a conservative experimental approach, we use a user-driven approach where we identify application scenarios through engaging with users in context.

AR systems with Potential for Home Use

While the home environment was not the focus of AR research, some past results indicate that there is a high potential for deploying technologies at home, and a large variety of applications that may be useful at home have already been developed. Yet this design space has not been systematically explored so far. Among the few past efforts in this area was the counterintelligence AR kitchen [5]. This was an augmented kitchen with informative projections overlaid on kitchen objects to enhance the cooking experience by making it more accessible, safer, more interesting, and efficient. The results showed the advantages of using cues in locating items, and also the disadvantages of using digital recipes over paper ones. Another AR system based on a projector-camera system was developed by Gugenheimer et al. [16]. They investigated use-cases for such a system based on interviews

and identified information and entertainment delivery as the highest demanded scenario.

Another topic addressed by AR research that could find its use at home was providing augmented senses. Fan et al. built SpiderVision [10]; a device that extended the field of view of the human eye. People using this device adapted to using a backward-facing camera as a 'third eye' attached to the back of their heads. Through AR technology, Jang and Bednarz enabled users to perceive and interact with real-time data provided by smart-home sensors [19]. They envision extending this concept to other domains like health. The AR health Application Mime [9] helps patients to analyze their blood at home. In this case study Djajadiningrat et al. illustrate the challenges of unassisted care at home and highlight that AR can act as an in-context manual for a novice user.

These design examples have shown that potential applications of AR may find use at home, helping users in everyday tasks and increasing their safety. In order to deploy these technologies in everyday settings, we must first know if and how they can be integrated into home environments. Our work aims at providing insights that could help translate existing knowledge about designing AR applications to design for the home.

Studying the Experience of Technology at Home

Our work uses a probe to study AR technology at home. Cultural Probes were first initiated by a group of designers under the lead of Bill Gaver. They wanted to explore new techniques to increase the engagement of the elderly in their local communities [4, 13]. The probes are inspirational objects designed specifically to prompt users to record their private life, ideas, and experiences [23]. The term 'cultural' indicates the type of technique used. Thus, it can be replaced with other techniques such as empathy or technology [4]. Probe kits can include items such as disposable cameras, maps, stickers, lists of instructions, diaries, illustrated cards, and pre-stamped postcards accompanied by open-ended provocative tasks [23].

Gaver and his team describe the probes to the participants as a tool through which designers could understand users and vice versa. Probes create a bi-directional understanding between the designers and the participants [13, 14], allowing users to become active co-creators in the design process through giving the designers the chance to deeply understand their culture, aspirations, dreams, and needs [4, 31]. What is important to our work is that a probe is a practice-oriented alternative to social science approaches to understand a user's environment [4]. Additionally, a probe can overcome problems in traditional data collecting methods such as limiting the view into a specific area, by acquiring an extended view into the user's life style [23]. However, traditional methods like interviews can also be employed as an assistant factor for probes to acquire a deeper insight into the user's life.

Culture probes are mostly used in two scenarios: First, exploring the implications of a new technology before making them publicly available[31]; and second, identifying problem statements, and exploring novel and creative ideas inspired by the participants. In this paper, we are more concerned with the first usage. Although prototyping techniques seem efficient in such cases and can be used to simulate the interactions with new technology, they would not guarantee the same deep understanding of active engagement of participants [31].

In this work, we utilize the concepts of cultural probes in terms of a technology probe to investigate AR in domestic environments. The extensive history of probes in HCI inspired us to explore AR at home using a probe.

3 RESEARCH QUESTIONS

Past research in the applications of AR has shown that AR solutions can be effectively built for a variety of scenarios. Yet, the majority of these cases was proposed by researchers and commercial system designers to explore the technical opportunities offered by AR, focusing on work and entertainment scenarios. Here, we take an alternative approach where we investigate how users perceive possible uses of AR. This approach leads to high ecological validity and further provides empirical validation of previous research. We focus on the following research questions:

RQ1 What are the users' attitudes towards the introduction of AR at home?

RQ2 What are the usage scenarios that users (in contrast to experts) perceive as most promising for domestic AR applications?

RQ3 What are the constraints and opportunities that AR applications envisioned by users pose to the design of future systems?

4 METHOD

As the design space for AR at home is broad and currently unstructured, our inquiry had a broad starting point. Thus, we adapted a two-fold approach to exploring the RQs. First, we used a survey to gain an initial impression of user attitudes towards AR and identify the areas and applications at home that users found most promising. The survey allowed us to involve a broad sample of users and thus a more general exploration.

Based on the survey results, we designed a more specific study focusing on the experiential aspects of AR at home and the practicalities of possible domestication. Our second

method was a technology probe that prompted users to explore usage scenarios and contribute ideas on how AR could be useful at home.

The hybrid approach we adapted enabled us to explore the design space of AR in a comprehensive way, addressing opportunities, challenges, and threats. In the following sections, we provide detailed descriptions of the two studies and later summarise their results.

5 ONLINE SURVEY

In order to explore the potential for designing engaging and meaningful interactive AR experiences at home, we decided to perform an online survey that investigated how users envisioned the applications of AR technology in a domestic environment.

Survey Description

The survey began with a short explanation of the concepts behind AR, followed by two examples of AR applications. Then we asked participants to go on a mental walk through the rooms of a conventional flat: the living room, kitchen, study, bedroom, and bathroom, and asked what artefacts or experiences the participants would like to augment and what functionality or information they would expect. An open text field was used to provide the descriptions. Subsequently, we asked what interaction modality they would favor and why, and encouraged them to write a story of how they could effectively use AR in their everyday lives. Finally, we asked for their demographic information and their technical background. The survey questionnaire is available as supplemental material appended to this paper.

Participants

We promoted the survey via social media and our university's mailing lists. In total 60 participants (31 female, 26 male, 3 other) answered the survey completely. Participants spent between 7 and 36 minutes ($M = 19.2\,min, SD = 8.3\,min$) answering the questionnaire. The age of the participants was between 16 and 60 years ($M = 29.07\,y, SD = 8.88$). Participants received no compensation. Of all participants, 36 had at least undergraduate education and 21 of them had a technical background. They rated their own experience with AR on a 5-point Likert scale. The answers showed that knowledge of AR in the sample was largely limited ($median = 1$). Additionally, 13 participants reported having experienced Virtual Reality (VR) before.

Results

We analyzed the open text responses using a pragmatic approach with open coding [3]. Only complete survey responses were analyzed. One researcher coded an initial sample of the data to establish a starting coding tree. This coding tree was then used by two researchers to code the rest of the gathered material. Finally, in an iterative discussion session, a final coding tree was established. Based on the codes, we identified general categories of opportunities for AR at home, which are presented below.

Table 1: Top three artefacts which participants of the online survey suggested to augment with. The artefacts are sorted by room and relative frequency.

	living room	*kitchen*	*study*	*bedroom*	*bathroom*
1	television	fridge	computer	wardrobe	mirror
2	couch	oven	desk	alarm clock	shower
3	(book-)shelf	pots & pan	documents	wall	cosmetics

Substituting Devices. Users often discussed replacing existing physical objects from their homes with virtual replicas tied to a dedicated position in the home. Many participants proposed to substitute one or more of their regular media displays. Participants often desired to replace their television set or desktop computer display. Besides the space-saving, participants highlighted the option to use multiple or larger screens.

> *I would augment my keyboard with multiple large displays. That would save a lot of space. –P19*

Other appliances that were considered for replacement were alarm-clocks, radios, and timers. Participants envisioned more intuitive user-interfaces to interact with the digital replica more easily. Table 1 shows the three top suggested device for each room of the hypothetical flat.

Enhanced perception. The participants of our online survey also considered how the utilization of AR could offer them new possibilities to perceive their environment. They suggested using amplified vision that allowed them to inspect closed storage, e.g. a wardrobe or refrigerator to know its contents, and in the case of the fridge, the expiry dates of the items within.

> *Augmenting the fridge would give me a quick overview of what will expire soon. –P114*

The primary motivation to visually inspect the fridge was to keep track of the available groceries and their best before dates to prevent unnecessary dumping.

The enhanced perception was also imagined to augment beverage cartons, kettles or trash bins to indicate the level of milk, water, or garbage. Additionally, participants suggested that enhanced perception could support users to visually perceive the temperature of water in a tub or kettle. Others proposed to augment their kitchen tools and get instant feedback on volumes of pots or boxes to better estimate if they could hold a specific amount of food or liquid.

On-Demand Information. Participants considered distributing information and media freely around their households,

which would improve their productivity and organization of daily tasks. Typical scenarios were news, weather or calendar entries displayed on appliances and furniture like fridges, wardrobes or corridors and support clear information retrieval.

> *A calendar display next to the vestibule could visualize what I need to deal with next. –P74*

Information in the environment often came accompanied by on-demand recommendation systems. Users expected AR to provide context-aware recommendations. Reported scenarios included hair, shave and make-up styling tips in an augmented mirror or clothes suggestions based on calendar events or weather forecast. In another scenario, participants pictured a couch that was augmented and visualized the time an occupant spent there unwinding or watching TV and possibly motivate them to live a healthier and more active life.

Interaction. In the online survey, we also asked the participants to think about the preferred and convenient interaction modalities. Most of them stated that, in a domestic environment, natural speech interaction was the modality of choice. They highlighted the benefit of hands-free interaction to be very favorable.

> [...] *during cooking I don't want to touch anything with dirty hands. I would prefer voice interaction. –P139*

However, gestures were also perceived as useful and convenient to use when limited to short interactions. Interestingly, some participants stated that they preferred no direct interaction with augmented artefacts. They rather considered AR in a domestic environment as an intuitive interface to consume information more efficiently.

6 TECHNOLOGY PROBE

Next, we endeavoured to build a deeper understanding of the possible augmentations for everyday objects that we observed in the survey. As survey participants were eager to suggest AR solutions, we also explored what potential benefits of AR they identified and they anticipated their experience of everyday tasks to change when using AR. In contrast to Hutchinson et al. [18], we used a hybrid methodology that combines a technology probe with photo elicitation.

We encouraged participants to generate AR user scenarios and interact with the technology. We combined a complete introduction to AR with a photo elicitation approach [15] and pre- and post-study semi-structured-interviews using the contextual laddering technique [34] to explore implicit insights on domestic AR usage. To facilitate the photo elicitation, we built an application inspired by Snapchat. The application enabled the participant to quickly take pictures and annotate them with stickers, emojis or text. All annotations were freely positioned, scaled, and rotated. After annotating, the original and annotated images were automatically saved to a cloud service. In contrast to previous works, where disposable cameras were deployed [13], storing images in the cloud allowed us to observe the study process remotely. Each participating household was given a Nexus 9 tablet with Android Nougat. The application including the user interface for annotating images is depicted in Figure 1. Thus, our solution combined the immediate access of a cultural probe with the illustrative benefits of photo elicitation. The study set-up enabled us to prompt users to imagine their desired experiences with AR and create them in a rapid. The visual qualities of an annotated photo helped communicate their visions effectively. This way, we opted for providing the participants with extensive means of expression rather than asking them to build prototypes.

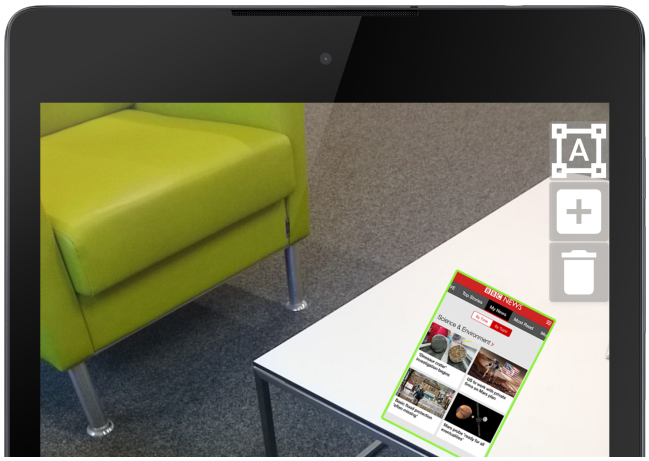

Figure 1: Tablet application to take pictures and annotate them. Top-right icons allow the user to add text and stickers or delete them. A news sticker is placed on the table.

Participants

We tried to invite a diverse set of people living in varying households. We managed to invite families, shared flat communities as well as couples who live together. Further, we attempted to ask people from different backgrounds. We conducted our technology probe with 13 participants in four households. All the households had two to four individuals. One household was a shared flat and one kept a cat. Participants (6 female) aged from 11 to 48 (mean = 26.8, SD = 10.8) took part in the technology probe and the interviews. Their occupations included pupils and students with different majors, teachers, consultants, and lawyers. Six were familiar with mixed reality applications, and one had used the Microsoft HoloLens before. Five participants had prior awareness of mixed reality through pop culture, fiction or documentary. Guardian consent was acquired for the participation of the minors in the study. Households ranged from 60

Table 2: Demographics and previews mixed reality experience (MRE) of the technology probe participants.

ID	*House*	*Occupation*	*Gender*	*Age*	*MRE*
1	H1	student	male	24	x
2	H1	undergraduate	male	22	x
3	H1	student	male	22	x
4	H1	graduate	female	25	o
5	H2	student	female	27	o
6	H2	student	male	20	x
7	H2	teaching assistant	male	27	x
8	H3	teacher	male	48	o
9	H3	teacher	female	46	o
10	H3	pupil	female	11	o
11	H3	pupil	female	13	o
12	H4	lawyer	female	33	o
13	H4	consultant	male	31	x

to 140 square meters (mean = 103, SD = 28.7) in size with two to six rooms. Table 2 shows details about the participants of the probe.

Procedure

The probe lasted for 14 days and was divided to three stages. We outline the stages below.

Introduction to Augmented Reality. Before starting the study, we visited the participants' households. We collected their consent for taking part in the study and processing the images, and conducted a pre-interview to collect their demographics as well as their experience with AR. We then introduced the participants into AR, based on the definition of Azuma [1]. Afterward, we explained the Microsoft HoloLens and gave each participant two small demonstrations. First, we showed them three holograms: a browser attached to a wall, a small city placed on a desk, and a globe set mid-space. Participants were instructed to walk around the holograms to understand that they are three-dimensional and fixed in the environment. Secondly, we demonstrated an interactive application which provides the ability to measure distances by placing two points in the environment. After setting the second point, a line connecting both points and the distance was shown. To prevent bias, we did not introduce speech and gesture interaction and used the provided clicker and gaze for interaction.

Start of the Probe. After the introduction to AR, we set up the tablet and explained the photo-elicitation application to the participants. We explained in detail how to take pictures, annotate them and save them to the cloud. Participants were asked to place the tablet in a location in the home that would be accessible to all participants of the household. They were also asked to document their ideas using pictures and annotations.

Semi-structured Interviews. After 14 days, we revisited the participants' households to conduct the semi-structured group interview. In preparation for the interview, we copied all annotated images from the cloud to a separate tablet and preselected ten annotated images based on uniqueness and relevance to the online survey results for a detailed discussion. In addition to Figure 2 a more extensive selection of annotated images is available as supplemental material appended to this paper.

The first part of the interview focused on general AR usage in a domestic environment. We asked questions to understand how the families imagined using AR on a daily basis. We continued with the ten preselected images to get deeper insights about the favorite use cases and most useful situations. Participants had the chance to skim through all pictures afterward to recall any situation not mentioned before. The second part of the interview concentrated on social implications, concerns, and form factor.

We audio recorded the interviews and transcribed the interviews verbatim for post-hoc analysis. In an initial round, two coders used open coding to analyze 25% of the data gathered, then met to establish a coding tree. One researcher analyzed the remaining material. A final meeting was held to refine the coding tree and establish the emergent themes.

7 FINDINGS

In this section, we present the findings of our probe. All study participants were positive towards the prospect of using AR every day. Most participants requested that AR capabilities be embedded in objects that they were already using or wearing such as spectacles, even so, they used a tablet throughout the study:

> *Since I need glasses anyway, I would definitely wear it all the time. –P2*

Further, we observed that some users welcomed features that required AR to be perpetually active. One wanted to use AR-based reminders because they considered themselves forgetful:

> *Well, I would definitely wear it all the time because I know I'm someone who needs to be reminded. –P3*

In contrast, some participants indicated that they envisioned that the usage of AR should be limited to the privacy of a home. They believed that AR devices could be problematic in social contexts:

> *I would rather use it in private situations when none is around. I don't think that's appropriate in a group. –P9*

We observed that, despite different views on the depth of AR adoption, all users contributed eagerly to possible users' scenarios and described their experience with AR extensively

in the interviews. Our data analysis process revealed five themes of the experience of AR domestication: assistance, enhancing perception, social activity, device augmentation, and concerns. Next, we describe the themes in detail.

Assistance

We observed that participants often saw AR as a way to provide contextualized assistance. Users were eager to contribute new ideas for scenarios in which AR could overlay additional information. The context of specific actions was often explored. An often-mentioned use case was cooking:

> *First, we thought the recipe on the kitchen wall would be great, but then we figured out that we could have a real virtual coach who could stand next to you and assist you while cooking. –P8*

The family continued describing a fictional cooking scenario where a famous TV chef would provide cues on how to prepare the dish. They also reflected that they would have liked the cook to give them freedom and only appear when assistance was required. Participants also reported the desire to receive assistance based on location. Overlaying navigation cue using AR was mentioned by all households in our probe. One participant pointed to a scenario where they were riding their bike and both of their hands were holding the handlebars:

> *While riding my bike, I imagine navigation cues in front of my eyes. It could be so easy if AR was always around. –P11*

Further, participants recognized that AR could be useful in scenarios that required the use of their entire body. An often-mentioned use case was sports. One user imagined a virtual trainer who could provide necessary exercise instruction:

> *She (the virtual trainer) should see what I do and talk to me. I'd like it if someone was around to correct my mistakes to prevent injuries. –P12*

We also observed that users were eager to use AR in tasks that require an extended sense of spatiality, i.e. getting an overview of a larger space, dealing with distances between objects, spreading or aligning artefacts evenly. Home furnishing was one cited scenario:

> *For example, I could place the (virtual) shelf on the wall and check how it would look. Would it fit the new sofa that we are planning to order? –P9*

Finally, users would often cite AR as an opportunity to use their smartphone less in the context of assistance. Many participants remarked that information that they currently obtained using a mobile device could be displayed in the environment thus reducing the need for touch interaction:

> *You wouldn't have to pull out your phone and go to an app. The information would be shown to me directly in the real world, like the WiFi signal strength, for example. –P5*

Enhancing Perception

The participants in our probe also considered how the application of AR could offer them new possibilities to perceive the world. Users contributed insights on how they would like AR to augment their senses. One participant expressed that they would like AR glasses to replace conventional corrective spectacles:

> *It would be great if I did not have to change my reading glasses and varifocals all the time. –P2*

Other users explored scenarios with more elaborate sensing capabilities that would give them new skills. For example, mood detection was discussed in one of the households:

> [...] *if you could actually see a mood of a person. –P6*

Further, participants wondered if they could use AR to make themselves more aware of possible dangers or consequences of their actions:

> *What is bad for the environment OR what am I allergic to... I am wondering if there are any toxic or environmentally harmful ingredients in the shampoo. –P3*

Obtaining additional non-sensory information about the environment was another often-cited case. Some participants wanted to interface with the history of the surroundings:

> *I would like to see additional information for a specific building or place of interest. For example, how did people live here back in the old days? –P8*

We also noted that participants desired not only to be more aware of the properties of their environment but also about other people. A father expressed a wish for AR to allow him to monitor his children better:

> *If you have a baby and you are in the kitchen and the baby in the living room, I want to see the baby without leaving the kitchen. Like X-ray vision. –P13*

Social Activity

Next, we show how participants imagined the role of AR in various social settings. All of the households recognized AR's potential to offer remote presence. One participant considered using AR to socialize instead of commuting to a sewing group meeting, which was troublesome. Interestingly, they suggested that using AR would enable them to participate in an organized group activity while still enjoying the comforts of their own home:

> *It is very time-consuming, and the sewing machine is heavy, but I like going to the meetings. Having a virtual meeting would be great. You could talk and listen to the people and the course instructor while working on your machine at home. –P2*

Our participants also expressed that they envisioned AR helping with social coordination. Users built scenarios where a cue embedded in the environment provided a point of reference and helped build mutual understanding. One user

Figure 2: Four images created during the technology probe. From left to right: Assistance during exercise, enhanced perception due to magnifying glasses, an augmented stove with smart timer, and a door providing plenty of valuable information. A more extensive selection of annotated images can be found in the appendix of this paper.

reflected that the process of choosing a film to watch could be more effective if augmented with AR:

If we planned to go to the cinema, we'd look together at the program. It's great when we see the same information so you can point to it. –P10

Some Participants remarked that they were open to sustained presence through VR and willing to engage with a virtual character over longer periods of time. Engaging with virtual companions through AR was an interesting perspective:

Having a virtual pet, like a Tamagotchi 3.0, could prevent someone from feeling lonely, or ensure that the family is ready for a real pet. –P13

Sharing content through AR and simultaneous media access was also seen as beneficial. Users remarked that AR offered opportunities for rapid media sharing with specific counterparts:

It would be wicked if I could share an article I was reading with a housemate just with a swipe. –P2

Augmenting Devices

Another observation that emerged in our study was that users often wished to use AR to add new or better functionalities to devices they already possessed. As household artefacts were considered well integrated into the home environment, AR presented the opportunity to enhance the device without interfering with its structure or simply needing to buy a new better one. For example, one user reflected how AR could enhance the experience of weighing oneself:

AR glasses could display a scanned image of the body and visualize how much body lean and fat you have and a compare how it was four weeks ago. –P3

Device augmentation was not only to be performed at home. Participants also remarked that they would use it for daily shopping:

First, it (shopping list) is in the kitchen, then it is attached to the shopping cart, and I can tick items. I could freely walk through the store and glance at the list without picking up my phone all the time. –P6

Another user expressed the wish for AR to enhance their perception of quantities in the kitchen. They believed that AR could increase their cooking repertoire and enhance cooking skills simply by providing extra information and reducing the need for new equipment:

I've no idea how to bake because the amount of butter or some ingredients are always so exact and I don't have some volume measure - I only have some random bowl or plate [...]. Since AR can measure distance and areas, I guess maybe it could help me to measure ingredients. –P7

We also observed that users requested functionalities that many commercially available household objects already offer. In the following passage, the user requested an AR-based indicator for pan temperature, while pans with built-in temperature gauges are now easily available.

I would like something to tell me that the pan is relatively hot at the moment and I can start cooking. –P6

Concerns

Here, we note some negative reactions that the perspective of using AR every day produced in users. These primarily fell into two categories: privacy and information overload.

Privacy. The users in our study understood that extensive sensing was required to offer them an AR experience. As a consequence, they were worried that future AR devices

would constantly record their actions and thus pose a threat to privacy:

> *The glasses sense all the information around me. Everything that the camera, microphone and other sensors can capture. –P9*

In contrast, AR was also perceived as a way to embed confidential information in the environment. Users envisioned that an AR system would control access to parts of the AR environment and only allow specified users to see parts of the AR world:

> *Wi-Fi passwords, something only housemates can see* [...] *the benefit is that I am the only one seeing the information and no one else. That means I am not disturbed by others while sitting in public transport. –P8*

On a larger scale, one user proposed to adorn the house for a social gathering. Here, only invited or paying guests could enjoy the visually enhanced location:

> *It would also be interesting if you want to do decorations. It's good for a party, and then everyone who's invited can see it. –P2*

Information Overload. Another concern was receiving too much information. Some users were afraid that excessive information embedded in the surroundings would provide too much stimulus and overwhelm them:

> *I am concerned that I get too much information all the time. Information should be presented only on request. –P9*

Further, participants recognized that a possible future proliferation of AR would imply the need for finding new ways to manage and prioritize information. One user commented that they would require a systematic way to access information in AR:

> *If information comes to you all at once, it is a little bit too annoying, but if there's a way that it can be systematically organized, and it is prioritized in such a way that the most important one is at a particular point, this is something I'll definitely always wear. –P2*

8 DISCUSSION

We explored the design space of AR at home with two studies and found that users reported a large variety of possible usage scenarios. Our results show that users generally welcomed AR as part of their everyday experience.

AR systems as personal technologies

Firstly, our studies showed that users envisioned using AR for personal means, in personal spaces, which is in stark contrast to what the majority of past research efforts explored [8]. The initial survey showed that AR was perceived as useful all around the home and our interviews showed that users envisioned employing AR even in simple tasks. This suggests that there is space for new exploration for HCI, widening the domestic frontier of AR applications. While past efforts explored AR's affordances for rendering complex tasks simpler or aiding in coordinating, our work shows that users expect AR to be deployed in more simplistic tasks. Next, we summarise more detailed findings and discuss challenges and opportunities for future work on domestic AR.

AR is primarily a means of providing assistance

We observed that users were highly interested in AR providing ASSISTANCE throughout the day. While we do recognize that this may have many positive effects, such as fostering good habits or skill development, ubiquitous assistance may pose some problems. The threat of providing too much help and essentially rendering everyday life boring is a known issue [25]. Our study shows that this potential issue is very relevant in the case of domestic AR. Thus, future designs of AR for the home should prioritize engaging experiences to avoid rendering everyday life facile. AR was often seen as a smartphone replacement or even a substitute for other information artefacts (e.g. replacing one's paper shopping list). This implies that past opinions in the literature about the blurring boundary between mobile interaction and AR [11] are also perceived by everyday users. While these uses may seem attractive to the users in the photos they contributed, it remains a challenge for HCI to explore how effectively AR could replace well-established interaction modalities.

Enhanced perception was an expected benefit of AR

Participants in both studies were eager to enhance their sensory perception through AR. This may have many benefits such as an increased awareness of environmental dangers or a better understanding of their natural surroundings. As we observed in the CONCERNS theme, users are aware of their limited cognitive capacity. As enhanced senses generate vast amounts of information, cognitive overload becomes a threat. Further, as our senses are biologically limited, channeling additional sensing input through AR may interfere with regular vision thus essentially limiting perception. While augmented perception offers interesting opportunities, designers must be wary as the consequences of amplified perception have not been fully explored [28]. The users' willingness to accept augmented perception systems at home offers an exciting opportunity for new designs, but it also calls for making sure that augmented sense systems are safe and reliable.

AR-enhanced household goods are likely to be domesticated

We observed that users were eager to augment everyday objects with functionalities provided by AR. Participants in the survey listed many objects and probe participants provided many examples in the AUGMENTING DEVICES theme. This implies that future household goods could take simpler forms

as some controls may be replaced by AR. Augmented household goods can not only lead to increased aesthetics and reduced production costs but also enable more customization. These findings resonate with past work by Gugenhemer et al. [16], where users proposed to replace or enhance the functionalities of household goods. The fact that users find turning everyday objects into interactive artefacts implies that many existing techniques for augmentation, e.g. WorldKit by Xiao et al. [36], can be deployed at home. We observed users envision interactions similar to annexing real objects as proposed by past work [17]. Our study shows that the domestication of AR may have implications for the design of household goods. As a consequence, designers of future interactive artefacts for the home should consider enabling AR-based functionalities. Further research is required on how existing AR techniques can be effectively applied to existing domestic artefacts.

Privacy and transparency are critical factors for AR

We noted that some users expressed concern about whether AR could be used in all social contexts or if it could produce information overload. This highlights the need for further work on context awareness for domestic AR. Further research is required to understand how to design privacy protocols for AR at home. Further, our findings show a need for developing AR interactions that respect existing social structures [29] and support SOCIAL ACTIVITY. As AR is already used in social settings, most prominently through the game Pokémon Go [24], future AR applications will need to effectively navigate social structures, especially if they are to be used at home. In the survey, users envisioned that AR may enter all rooms in their homes. This poses the challenge of designing AR technologies that support social coordination and acceptability. New social contacts about AR at home may be required, as suggested by past work [7]. Consequently, designing AR systems that respect the users' privacy and communicate openly on how the users are protected is necessary for AR to enter the domestic application area.

Limitations

While our probe and survey were designed to be comprehensive and address a wide user group, the studies are prone to certain limitations. Firstly, we recognize that our work surveyed only a Western European population and we can not generalize to the general population. The domestication of AR is certainly affected by cultural factors that should be studied in future work.

Further, we see that, for financial and legal reasons, we were not able to let families use the HoloLens or any other advanced AR device over a longer period of time. While we are confident that our Snapchat-like app elicited rich feedback from the users, deploying a fully functional AR device in the household may have offered more ecological validity. To the best of our knowledge, none of the currently available devices can offer a lightweight head-mounted-display experience that would enable spontaneous experience sharing. Consequently, our design emphasized the serendipity of idea generation over staying true to the form factor. We recognize that a different focus may have yielded alternative results.

Finally, we recognize that visions of AR are highly present in mainstream media and thus produce a certain hype effect in users. In our analysis, we tried to focus on recurring patterns and themes to reduce the impact of the novelty effect. However, we recognize that users' attitudes towards the domestication of AR will evolve over time and further studies will be necessary to fully understand the rich user experience of AR at home.

9 CONCLUSION

This paper explores how Augmented Reality (AR) can blend into our homes and how users can benefit from it in a domestic environment. We conducted an online survey and a technology probe to explore potential AR domestication. The survey helped us identify initial opportunities for exploring the design space of AR at home. Later, we explored these opportunities in detail in the probe. We developed a tailor-made mobile application to enable users to suggest possible AR applications at home. From the photos and semi-structured interviews, we identified and discussed five themes of domestic AR: assistance, enhancing perception, social activity, device augmentation, and concerns.

Our results showed that concerns about privacy and transparency exist, but participants were eager to experiment with AR and saw great potential for long-term use. We highlighted that future systems should carefully choose the degree of assistance provided, avoid cognitive overload when designing for augmented perception, explore the design space of AR-enhanced domestic equipment and derive new privacy and transparency rules for domestic AR.

In the future, we would like to apply these insights to existing technology and collect further quantitative data and qualitative insights on how AR experiences can be integrated into domestic practice. We hope that our work will encourage future research to explore AR prototypes that escape the comforts of a lab and enter domestic environments.

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