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Understanding Users' Preferences for Augmented Reality Television

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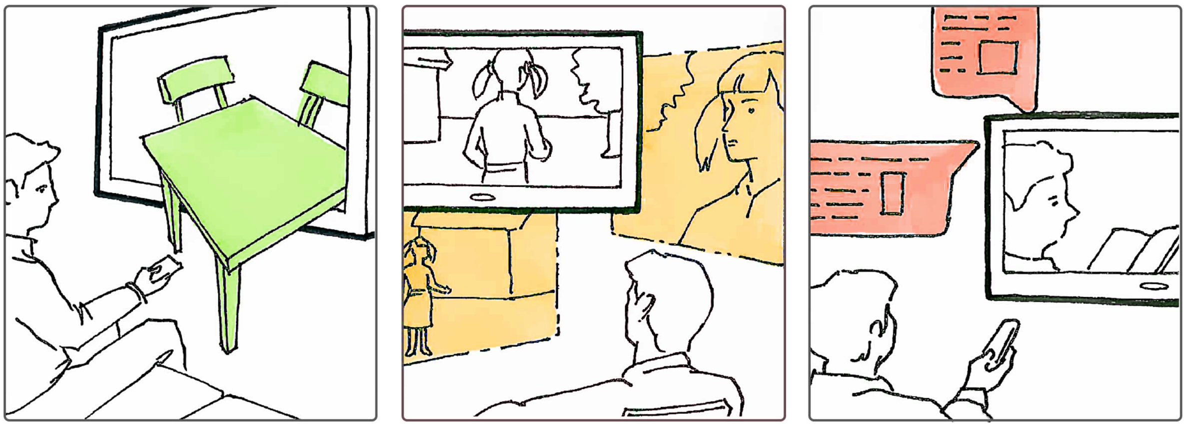

Figure 1. Artist illustrations of three of the twenty scenarios examined in this work to uncover users' preferences for and perceived value of Augmented Reality for television: virtual objects coming out of the TV screen (left image), watching different perspectives of the same movie scene (middle image), and having access to additional content, such as the names of the characters from a movie, displayed next to the TV screen (right image).

Abstract

We examine users' preferences for Augmented Reality for television and report findings from an exploratory study with 172 participants we conducted to understand the perceived value of twenty distinct AR-TV scenarios. We connect our findings to participants' overall perceptions of and experience with AR technology as well as to their self-reported television watching behavior. Our results reveal high perceived value for AR-TV scenarios involving interactive content, wall-sized and room-sized video projections, multiple perspectives of the same movie scene, and for virtual objects coming out of the TV screen into the room. Other scenarios, such as live video of remote friends watching the same broadcast or multiple virtual channels displayed around the TV screen were rated less valuable.

Index Terms: Human-centered computing—Mixed/augmented reality; Human-centered computing—Empirical studies in HCI.

1 Introduction

Recent advances in home entertainment have enabled increasingly sophisticated features for smart TVs, such as delivery of on-demand and Internet-based content, dedicated apps for second-screens [16, 17], voice recognition [25, 40], gesture-based [34, 39, 48, 53, 60], spatial [33], and tangible user interfaces [13, 36] to control the TV set, multisensory experiences for storytelling [54], accessible television [56, 57], and new ways for the TV to mediate social interaction for viewers [50]. Today, seven out of ten TVs sold around the world are smart TVs, and the smart TV market is expected to reach 67 billion U.S. dollars by 2025 [42]. At the same time, Augmented Reality (AR) has evolved from a mere concept and early prototypes living inside the premises of research labs [5, 28] to applications that can be readily downloaded and installed on smartphones, tablets, head-mounted displays, and AR glasses [2, 11, 26, 27], with a global market expected to grow to 90 billion U.S. dollars by the year 2020 [43].

In this context, it was expected that the smart TV and AR markets would merge to deliver users with rich, augmented experiences during television watching, *i.e.*, AR-TV. For example, wall-sized [22, 49] and room-sized [21] video projections have been explored by creative researchers to bring content out of the TV screen into the physical room, close to viewers. The industry has also started to look into repurposing second-screens, such as smartphones and tablets, into devices for rendering AR content for television [4]. However, in the rush towards technological innovation, a fundamental question seems to have been left out: *What do viewers actually want in terms of AR-TV*? The literature on AR and interactive television (iTV) has remained silent on this aspect, which unfortunately impacts design of effective AR technology that would bring value to the TV industry and its end-users. In fact, we reached a point where we realize the opportunity of AR-TV [4, 8, 10, 21, 22, 35, 49, 50], but remain blind to viewers' preferences regarding what kind of AR-TV experiences they expect, perceive valuable, and would enjoy during television watching. In this paper, we make the first step towards understanding preferences for AR-TV scenarios. But before moving on, we introduce our definition for AR-TV employed in this work.

1.1 An Operational Definition for AR-TV

We introduce a definition for AR-TV by adopting Azuma's [5] three characteristics of AR systems (*i.e.*, real-time interactiveness, 3D, and mixing virtual and physical) and IFIP TC14.6's three-level taxonomy (*i.e.*, edit-share-control) from iTV research [18]:

> ***Definition:*** AR-TV is an immersive, real-time interactive digital experience in 3D centered on the TV set.

1.2 Context and Contribution

Although television consumption is gradually shifting from the traditional, linear TV to on-demand, Internet-based, and mobile television, the TV screen itself is still relevant and predominant in the TV landscape. For example, according to Nielsen's 2017 Local Watch Report [30], 93% of streamers watch traditional TV on a typical day,

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while Zenith's 2018 Media Consumption Forecasts [61] reports on the TV remaining dominant as the growth of mobile media levels out. The TV is still the largest screen in most households and, while live broadcast and cable viewership may be declining among younger viewers, the demand for TV content has not necessarily decreased. In this context, looking at AR applications and AR content centered on the TV screen [22, 47, 49, 56, 57] is relevant for current trends and forecasts in iTV. However, we know very little today about end-users' preferences regarding what kind of AR-TV experiences they would enjoy and perceive valuable.

In this paper, we conduct an investigation of users' preferences for AR-TV and report results from an exploratory user study, for which $N=172$ participants shared their understanding and use of AR devices and applications, their television watching behavior, and their preferences regarding twenty distinct AR-TV scenarios, three of which are illustrated in Figure 1. To the best of our knowledge, this is the first large-scale survey study looking into what users want and find valuable regarding AR-TV, an important step for providing directions for future AR-TV services and applications.

2 Related Work

We discuss in this section prior work on AR systems and applications with a focus on devices, use-case scenarios, and studies for television and home entertainment.

2.1 From Generic AR Systems to AR-TV

AR has seen a remarkable evolution with applications in many areas [5, 45], such as gaming, e-commerce, mobile computing and, recently, home entertainment and iTV [22,47,49,56,57]. For example, a review by Thomas [45] on AR gaming reported implementations on many platforms, such as tabletops, see-through displays, wearable computers, hand-held devices, helmets, and systems based on video projections, revealing an accelerating field of research that is moving towards ubiquitous consumer AR systems [7]. Mostly available today in the form of apps for smart mobile devices, the purpose of any AR system is to enhance its users' perceptions of the reality, usually captured by video cameras, on top of which virtual objects are superimposed. To this end, an AR system combines the real and the virtual, is interactive in real-time, and registered in 3D [5]. These characteristics apply to AR-TV systems as well, for which the immersive, real-time interactive experience is centered on the TV and implemented using smartphones [8, 10], multilayered TV content [50], wall-sized and room-sized video projections [21, 22, 49], and head-mounted displays and AR glasses [26, 27, 56, 57]. AR technology has also been used to create TV content. For example, "ARSTUDIO" [12] is a virtual studio system that adds special effects in real time as opposed to post production methods.

AR technology presents a series of pressing challenges that need to be overcome for the user experience (UX) of AR applications to improve. For example, in a survey conducted about AR UX, Irshad *et al.* [20] reported users' favorable appreciations of the playful experience delivered by AR applications, their well designed digital controls, and ease of use, while other UX aspects, such as response time and the captivity of the experience [20], were less positively evaluated. Azuma [6] outlined the pressing problems that AR platforms and applications still need to overcome, such as precise tracking and pixel-accurate registration, wide field-of-view see-through displays in compact form factors, new interfaces to control AR systems, and the need for a better semantic understanding of real-world objects in large-scale environments. Besides these general challenges for AR technology, Popovici and Vatavu [35] have recently identified nine key aspects for the design of visual augmentation of the TV watching experience, such as the need to better understand users' preferences and desires for AR-TV, moving from smart TVs to smart TV environments, addressing augmented TV for viewers with visual impairments, and accelerating research from multimedia to smart, augmented ambient media, among others.[1]

2.2 AR-TV

Prior work has considered applications of AR to home entertainment, including iTV. For example, "IllumiRoom" [22] used video projections around the TV set to expand the field of view beyond the physical TV screen, creating a richer and more captivating gaming experience for users compared to traditional gaming restricted to just one screen. The space around the TV set has also been explored for multi-screen TV systems, such as in the "Around-TV" concept and prototype of Vatavu [49] that demonstrated an interactive system with customizable TV screens, widgets, and user interface controls. AroundTV enabled viewers to create virtual screens video-projected on the wall behind the TV set and drag content freely between the physical TV screen and the space around it. Vatavu and Mancaş [51] later referred to such multi-screen systems as "interactive TV potpourris." Other systems expanded video projections to the entire room to create immersive experiences for their users [21, 32]. An example is "RoomAlive" [21] that employed several video projectors and Kinect sensors to create an augmented environment where users were submerged into the game with virtual objects displayed basically anywhere in the room. The "Room2Room" system [32] implemented face-to-face conversations in the form of life-sized telepresence by video projecting interlocutors on empty chairs.

Other approaches to AR-TV considered mobile devices [8, 10], superimposition of digital content on top of the TV transmission [19, 50], and memory-based user interfaces [33]. For example, Baillard *et al.* [8] proposed a multi-screen system visible to the user when looking in the direction of the TV through a tablet or a headset device; and Bibiloni *et al.* [10] used a hand-held device to display additional information about the TV broadcast. Another approach was demonstrated by Vatavu [50], who proposed "Audience Silhouettes," a concept and prototype that employed a Kinect sensor to capture the body silhouettes of remote viewers watching the same TV channel and display those silhouettes in real-time on the TV screens of peer viewers. Yet another approach to augment the physical space around the user's body during television watching was "Hover" [33], a system that enabled users to change TV channels by pointing to locations in mid-air, for which cognitive maps in the form of associations between physical locations and TV content [41] were specified during a configuration stage.

Head-Mounted Displays (HMDs) and AR glasses, such as Microsoft HoloLens [27] or Magic Leap [26], represent another suitable platform to implement AR-TV applications and delivery of AR content during television watching. For example, Vinayagamoorthy *et al.* [56] presented a system that displayed a virtual person performing sign language translation next to the TV set, visible to viewers wearing a HoloLens device. A follow-up study [57] evaluated ways to personalize the sign language interpretation experience, such as delivering signed content on the TV or next to the TV screen. As platforms and devices such as HoloLens and Magic Leap become mainstream, we can expect a large variety of applications for AR-TV. However, no prior work has explored users' preferences for AR-TV to date. Therefore, our literature review revealed a gap in knowledge in what users' find valuable regarding AR for television watching. The study presented in the rest of this paper tries to fill this void.

3 Study

We conducted a study to understand users' desires for and perceived value of AR-TV. Our method for data collection was based on online questionnaires, which allowed us to reach a large number of respondents with various backgrounds and occupations.

[1] See the research agenda for the visual augmentation of the television watching experience: `http://www.eed.usv.ro/~vatavu/projects/AR-TV`

3.1 Participants

A total of 198 volunteers agreed to participate in our online study, which we advertised via mailing lists, Facebook, and LinkedIn social and professional networks. Participants' countries of origin included European countries, such as Romania (most of our participants), Belgium, Germany, Italy, Czech Republic, Ireland, and the Republic of Moldova. Participants' professional backgrounds included a diversity of occupations, such as researcher, professor, IT engineer, software engineer, security consultant, optometrist, marketing manager, business owner, pharmacist, artist, sales representative, economist, web developer, medical doctor, flight attendant, or students of various disciplines. Communication with participants was conducted exclusively online. Following a preliminary analysis, we discarded the responses of 26 volunteers because of uncommitted participation, such as always entering the same answer to our Likert scale questions. In the end, the number of valid participants that we considered for the analysis reported in this paper was N=172. Participants' ages ranged between 17 and 70 years old (M=26.2, SD=7.3 years), and 63 respondents (36.6%) were female.

3.2 Task

Participants filled out a Google Forms questionnaire, which collected responses about their general understanding of AR, regular use of smart devices, television watching behavior, and perceived value of 20 distinct scenarios that we imagined for AR-TV. At specific points during the online questionnaire, participants were asked to watch the following YouTube videos demonstrating various AR-TV scenarios:

1. The "Augmented Reality Broadcasting Compilation"[2] illustrates examples of AR applied to broadcasting. Participants were asked to watch this video after they filled in their demographic information (the first part of the questionnaire) with the goal to make them aware of the possibilities offered by AR.
2. The video "Around TV"[3] showcases a multi-screen TV system using both a TV set and video projections around it [49]. Participants were asked to watch this video before answering questions regarding their perceptions of AR-TV to make sure they were familiarized with the AR-TV concept.
3. The video "IllumiRoom Projects Images Beyond Your TV for an Immersive Gaming Experience"[4] demonstrates the IllumiRoom system of Jones *et al.* [22]. Participants watched this video right after Around TV to gain more insight into gaming and home entertainment opportunities enabled by AR.
4. The first three minutes of the video "Augmented Reality on Your Television"[5] show a system that displays virtual content in front of or around the TV set. Participants were asked to watch this video after IllumiRoom to get more information about how AR could enhance the experience of TV watching.

These specific YouTube videos were selected to present participants with various perspectives on AR-TV, representative of the incipient stage of AR-TV technology, content, and application development at the moment of our study. These perspectives represent a mixture of visions for AR-TV, actual systems in production, and demonstrations of research prototypes. Watched together, the four videos depict a representative picture of where AR-TV is today but also where it could be in the future, necessary to create a common frame of reference for the participants of our study.

3.3 Hypotheses

Since our study represents the first exploration of end-users' preferences and understanding of AR-TV, we designed it to be *exploratory* rather than *hypotheses-oriented*. This way, "the flexibility in looking for data and open-mindedness about where to find them," both qualities of exploratory study designs [44], were approached to gather sufficient descriptive information to inform further explorations. To understand users' preferences for AR-TV, we employed several measures inspired by the practice of measuring UX [3] and by studies from iTV research [15, 38, 46, 50, 52, 57], which we present next.

[2]https://youtu.be/s8lb3JCNqcc
[3]https://youtu.be/XQ96C2Zolh0
[4]https://youtu.be/re1EatGRV0w
[5]https://youtu.be/lpj90PkfPJ8

3.4 Measures

We divided our questionnaire into five sections:

1. **Demographic information**. Participants provided information about their age, gender, and occupation. They also reported smart devices used on a regular basis by selecting from the following categories: *tablet*, *smartphone*, *smartwatch*, *smart fitness band*, *AR glasses*, *smart ring*, *wireless earbuds*, *smart TV*, *video games consoles*, and *other* (if *other* was checked, participants specified the devices they were using that were not in the list).

2. **Television watching behavior** was assessed using the following self-reported measures:

   (a) TV-HOURS, ratio variable, represents the number of hours per day spent watching TV. Since TV consumption can take various forms, such as traditional/linear, on-demand, or mobile TV [30, 61], we were interested in the overall time spent by our participants watching television, regardless of the device, service, and context of watching, to form an understanding of our participants' total TV watching time.

   (b) TV-GENRES, nominal variable, represents the genres regularly watched by our participants from the following categories (multiple selections allowed): *comedy/sitcoms*, *documentaries*, *education*, *game shows*, *music television*, *food and drink television*, *reality television*, *religious television*, *sports*, *telenovelas/soap operas*, *travel television*, *news*, *current affairs and political talk shows*, *movies*, *variety shows*, *cartoons*, *science and technology*, and *other*.

   (c) SECOND-SCREEN, ordinal variable, measures how often participants used another device, such as a smartphone, when watching television. SECOND-SCREEN was assessed using a 5-point Likert scale with items ranging from *"1, never"* to *"2, rarely"*, *"3, sometimes"*, *"4, very often,"* and *"5, always."*

   (d) TV-WATCHING-CONTEXT reports how participants usually watched television, with the following categories: *by myself*, *with friends*, *with family*, and *other*.

3. **Overall perception of AR technology** was collected using the following measures:

   (a) AR-MEANING, a free-form description of the participants' understanding of the concept of Augmented Reality.

   (b) AR-IMPORTANCE, ordinal variable, representing a rating on a 5-point Likert scale of the perceived importance of AR to our participants, from *"1, not important"*, to *"2, slightly important"*, *"3, moderately important"*, *"4, important,"* and *"5, very important."*

   (c) AR-EXPERIENCE, ordinal variable, measures how much experience participants had with AR devices and applications. AR-EXPERIENCE was assessed with a 5-point Likert scale from *"1, not at all"*, *"2, very little"*, *"3, somewhat experienced"*, *"4, good experience,"* and *"5, to a great extent."* To understand prior experience with AR, examples of AR apps that participants had used were also elicited at this stage.

4. **Perception of AR-TV**, for which participants were asked to rate the following characteristics of AR-TV using 5-point Likert scales with the following items: *"1, strongly disagree"*, *"2, disagree"*, *"3, undecided"*, *"4, agree,"* and *"5, strongly agree:"*

(a) USEFULNESS, as a reaction to the statement *"AR-TV is useful."*
(b) INFORMATIVE, *"AR-TV is informative."*
(c) DESIRABLE, *"AR-TV is something that I want for myself."*
(d) COGNITIVE-EFFORT, *"AR-TV is unnecessary cognitive effort during television watching."*
(e) FUN, *"AR-TV is fun."*
(f) SOCIAL-INTERACTION, *"AR-TV can help people in remote locations to enjoy social interaction while watching TV."*
(g) DISCOMFORTING, *"AR-TV is discomforting."*
(h) FUTURE, *"AR-TV is the future of television."*

5. **Preference for application scenarios for AR-TV**. Participants were asked to rate the perceived value of 20 distinct scenarios that we imagined for AR-TV; see Table 5. Ratings were provided using 5-point Likert scales with the following items: *"1, not valuable"*, *"2, limited value"*, *"3, moderately valuable"*, *"4, valuable,"* and *"5, very valuable."* We designed these scenarios by inspiring from visions and features of AR-TV systems described in prior work [21,22,47,49], current products for AR-TV [4,19], our previous experience with iTV and AR-TV [33–36,49,50], and by generating new ideas based on this prior work and experience through a creative procedure based on Bending, Breaking, and Blending [14]; see Table 5 for the full descriptions of the 20 AR-TV scenarios and Figure 1 from the first page for visual illustrations of three selected scenarios.

4 RESULTS

We report in this section results regarding participants' perceptions of and preferences for AR-TV. But first, we start with a discussion about the representativeness of our sample.

4.1 Representativeness of the Sample of Participants

Figure 2 illustrates the age-gender demographic distribution of our participants, showing good age coverage for both genders: female participants were between 17 and 50 years old, and males between 18 and 70. The age distributions were similar for the two genders (M=25.8, Mdn=23 years for male and M=26.8, Mdn=25 years for female participants, respectively) with neither the Wilcoxon rank sum test (W=3724, p=.354, *n.s.*) nor the Kolmogorov-Smirnov test (D=0.155, p=.254, *n.s.*) detecting any significant differences between the age distributions of male and female participants. Neither distribution was normal (as confirmed by Shapiro-Wilk tests, W=.807, p<.001 for female and W=.676, p<.001 for male participants), because of a larger representativity of young people, less than 35 years old, in our sample. However, this aspect is fortunate and actually favorable to our investigation, as it is a known fact that young people use a greater breadth of technologies compared to older adults and are more open to new technology, whereas older adults are more likely to use technologies that have been around for a longer period of time [31]. Although well balanced in terms of age and gender groups, our sample contains participants from European countries only and, thus, ignores cultural effects on the perception and use of AR and TV; see the Limitations section at the end of this paper for future work in this regard.

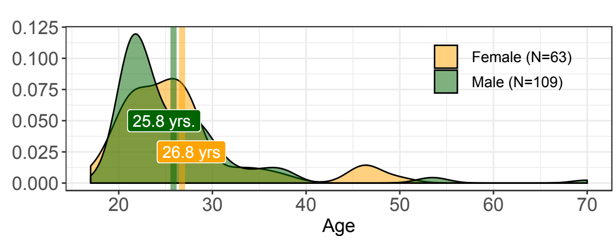


Figure 2. Density distributions of our participants' age-gender demographics.

Table 1. Devices used by our participants on a regular basis. *Notes:* clubs (♣) denote devices that can *render* AR and flowers (✼) devices to *interact* with AR.

	Smart device	N	%	AR-ready
1	*smartphone*	161	93.6%	♣ ✼ [20,55]
2	*smart TV*	57	33.1%	♣ [49]
3	*tablet*	33	19.1%	♣ ✼ [10]
4	*smartwatch*	26	15.1%	✼ [58]
5	*video games consoles*	21	12.2%	♣ ✼ [21,22]
6	*wireless earbuds*	19	11.0%	-
7	*smart fitness band*	18	10.4%	-
8	*augmented reality glasses*	3	1.7%	♣ ✼ [10]
9	*smart ring*	0	0%	✼ [29]

Table 1 lists frequency statistics regarding the use of smart devices on a regular basis by our participants, with the most used devices being *smartphones* (93.6%), *smart TVs* (33.1%), and *tablets* (19.1%). Also, three participants reported using *smartglasses*. The table also includes our notes regarding which device has been used or could be used to implement AR-TV, either to render AR content, such as smartphones, smart TVs, or smartglasses, or to interact with AR content, such as smart rings [29]; see the "AR-ready" column.

The analysis so far shows that the results we report in this work come from participants (i) of a variety of age groups, (ii) with similar age distributions for men and women, while (iii) the opinions of the age group most likely to adopt and use AR technology, *i.e.*, young people, were given more representativeness in our sample. Moreover, (iv) the usage of smart devices suited for rendering AR was compelling, *e.g.*, 93.6% coverage for smartphones. The next section reports our participants' experience with AR technology.

4.2 Experience with AR Technology

We asked participants to report their previous experience with AR devices and applications using a 5-point Likert scale, *i.e.*, the AR-EXPERIENCE measure. Most of our participants were either *not experienced* or *very little experienced* with Augmented Reality (33.7% and 39.0%, respectively), which is an expected outcome, as AR consumer products are at an early stage, still to penetrate the mass market [1]. A number of 36 participants (20.9%) declared themselves *somewhat experienced*, while 10 participants (5.8%) reported *good experience* with AR; see Table 2. Only one participant reported being *experienced to a great extent*, which is a surprising outcome, since our sample also included researchers and software engineers, who we knew for a fact to had been involved in developing applications for AR. It seems that there was a general bias towards self-reporting a lower AR-EXPERIENCE level, probably because of the novelty of AR, even for experts. However, when asked to rate the importance of AR, only 4 participants (2.3%) considered AR *not important* and 26 (15.1%) believed that AR was *slightly important*, while 53 (30.8%) reported AR *moderately important*, 64 (37.2%) *important*, and 25 participants (14.5%) considered AR very important to them. These results show interest in AR, which is gaining ground towards becoming a mainstream technology [1].

Table 2. Participants' self-reported experience with AR reveals a technology that is gaining ground, yet still to become mainstream [1].

	AR-EXPERIENCE (self-reported)	N	%	Age (years) Min	Max	Mean
1	*not experienced*	58	33.7%	18	46	24.3
2	*very little experienced*	67	39.0%	17	70	26.3
3	*somewhat experienced*	36	20.9%	21	50	27.6
4	*good experience*	10	5.8%	18	54	32.2
5	*to a great extent*	1	0.6%	21	21	21.0
	Overall	**172**	**100%**	**17**	**70**	**26.2**

Table 3. **Frequency statistics for the top-10 mostly employed words by each group of participants when defining AR.** ***Note:*** **The fifth group (*experienced to a greater extent*) included one participant only, so we do not report them in this table.**

	1, not at all experienced			2, very little experienced			3, somewhat experienced			4, good experience		
	Word	**N**	**Freq.**	**Word**	**N**	**Freq.**	**Word**	**N**	**Freq.**	**Word**	**N**	**Freq.**
1	reality	30	8.1%	reality	36	8.8%	reality	17	6.5%	world	5	6.5%
2	real	28	7.5%	real	28	6.8%	real	16	6.1%	digital	4	5.2%
3	virtual	18	4.8%	virtual	28	6.8%	virtual	11	4.2%	content	3	3.9%
4	world	17	4.5%	world	19	4.6%	world	11	4.2%	environment	3	3.9%
5	augmented	14	3.7%	objects	14	3.4%	environment	8	3.0%	real	3	3.9%
6	object	11	2.9%	environment	13	3.1%	augmented	7	2.6%	add	2	2.6%
7	technology	10	2.7%	augmented	11	2.7%	computer	7	2.6%	display	2	2.6%
8	computer	8	2.1%	digital	7	1.7%	object	7	2.6%	marker	2	2.6%
9	life	6	1.6%	experience	7	1.7%	generated	6	2.3%	new	2	2.6%
10	project	6	1.6%	interactive	7	1.7%	enhance	5	1.9%	reality	2	2.6%

Figure 3. Word clouds generated from our participants' definitions of AR. From left to right: participants *not experienced at all* (N=143 words), *very little experienced* (N=145 words), *somewhat experienced* (N=124 words), and with *good experience* in AR (N=56 words). *Note:* The fifth group (*experienced to a greater extent*) included one participant only, so we did not have enough data to generate the fifth cloud. The clouds were produced using the online tool from `https://www.wordclouds.com`.

To understand our participants better, we looked at their definitions of what AR meant to them, *i.e.*, the AR-MEANING measure. According to Table 2, five groups of participants were identified, according to their self-reported experience with AR. The definitions provided by the first group (*not experienced at all*) were diverse, ranging from a good understanding of the concept (*e.g.*, "Augmented reality is a technology to add virtual components in real time to a real world situation") to vague descriptions highlighting the technological novelty (*e.g.*, "Something new and interesting" and "Technology that helps you understand everything better"). In the second group (*very little experienced*), we found definitions referring to the idea of overlaying two distinct realities (*e.g.*, "A combination between virtual reality and real life"), but also more educated descriptions (*e.g.*, "[Augmented Reality] is an interactive experience of a real world environment that is augmented with contextual digital information"), emphasized by the use of specific words, such as "interactive" and "digital." Definitions of the latter kind occurred more frequently for the third group of participants (*somewhat experienced*) and ranged from simple, yet to the point descriptions of the concept, *e.g.*, "[Augmented Reality is] enhanced reality; adding virtual elements to the real world," to very elaborate definitions, such as "an interactive experience of a real world environment where the objects that reside in the real world are augmented by computer-generated perceptual information, sometimes across multiple sensory modalities, including visual, auditory, haptic, somatosensory, and olfactory." The definitions continued to abound in technical terms and concepts for the participants from the fourth and fifth groups (*good experience* and *experienced to a great extent*), *e.g.*, "Digital enrichment of the real world environment in a synchronized and content aware manner" and included technical details, *e.g.*, "To display some virtual objects on your smartphone, smart lenses, or some other device smart enough, the device needs to have a camera to read markers." Overall, the definitions provided by our participants confirm a good understanding of AR for groups 2, 3, 4, and 5 (see Table 2) as well as for some of the participants from the first group (*not experienced*).

Table 3 lists the top-10 most frequently employed words by the participants of each group when defining AR, and Figure 3 shows word clouds generated from participants' definitions, after removing uninteresting stop words, such as "the", "and", "for," etc. This data reveals interesting differences between the groups of participants, as defined by their self-reported AR-EXPERIENCE, in terms of a vocabulary changing from one group to the next. For example, the words "reality", "real," and "virtual" occur with the highest frequency in the first three word clouds, in contrast to the fourth cloud (participants with *good experience*), for which only the word "reality" is still present, but on the 10th place in the top-10 list. This result is determined by participants from the first three groups employing expressions such as "virtual reality", "augmented reality", and "real world" more often, while the fourth group employed more technical terms, such as "digital", "display," or "marker." The word "augmented" was used more often by the groups of participants with a lower self-reported experience, and it decreased in frequency from 3.7% for the first group to 2.7%, 2.6%, and 1.3% for the other groups, respectively; see Table 3. The fourth group (*good experience*) had the highest frequency of technical terms, such as "digital", "content," or "environment." Moreover, we noticed for this group the presence of the word "marker" referring to the tags used to display computer-generated content for marker-based AR applications.

4.3 Television Watching Behavior

Our participants reported spending on average 2.7 hours per day (*SD*=1.7 hours) to watch TV or Internet videos, such as YouTube channels. The top-3 preferred TV genres were *movies*, *science and technology*, and *documentaries* (72.0%, 67.4%, and 63.3%), while the least preferred ones were represented by *reality TV*, *religious TV*, and *soap operas* (8.7%, 7.5%, and 2.3%, respectively); see Table 4. Some participants reported watching *other* genres, not in our list, such as "animes", "YouTubers," and "financial education channels." The majority of our participants (151, representing 87.8%) reported watching television *alone*; 71 (41.3%) responded watching TV *with friends*; and 84 participants (48.8%) reported that they watched TV *with their family*.

When asked to report other devices used during television watching (*i.e.*, the SECOND-SCREEN measure), 19 participants (11.0%) chose the option *never*, 49 (28.5%) *rarely*, 60 (34.9%) *sometimes*, 33 (19.2%) *very often*, and 11 participants (6.4%) reported *always* using a smart device when watching television. This result suggests an interest in second-screen television watching that, together with the large adoption of smartphones (see Table 1), supports mobile devices as platforms for delivering AR-TV [4, 8, 10].

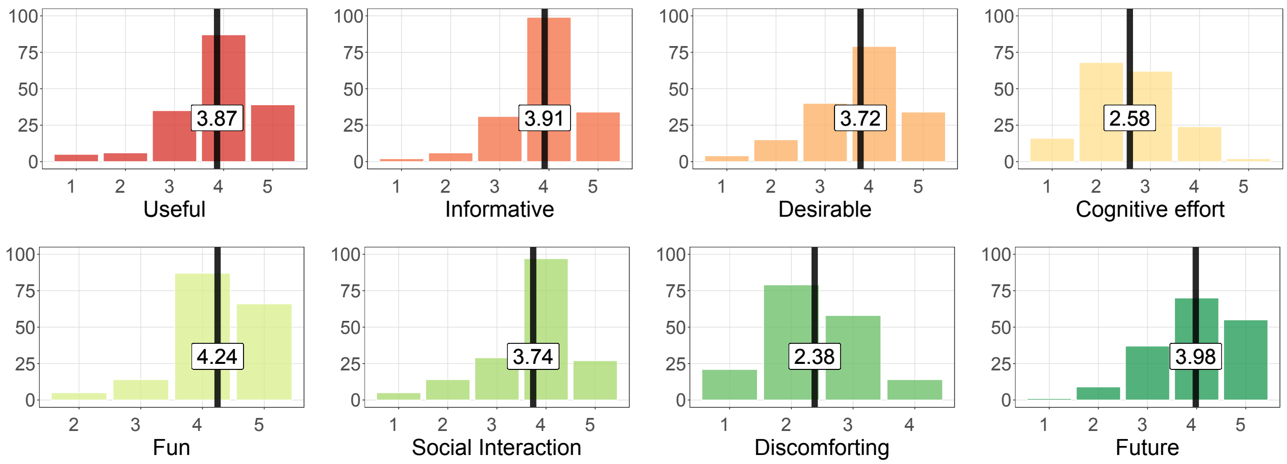


Figure 4. Participants' perceptions of AR-TV. AR-TV was perceived more *useful* (3.87), *fun* (4.24), and *desirable* (3.72) than *discomforting* (2.38) or *cognitively demanding* (2.58). *Note:* higher mean values denote more agreement with the statements to which participants were asked to react, *e.g.*, *"AR-TV is informative"*; see the Study section.

Table 4. TV genres followed on a regular basis by our participants.

	TV-GENRES categories	N	%
1	*Movies*	124	72.0%
2	*Science and technology*	116	67.4%
3	*Documentary*	109	63.3%
4	*Educational*	97	56.3%
5	*Comedy / sitcoms*	88	51.1%
6	*News*	68	39.5%
7	*Music television*	77	44.7%
8	*Cartoons*	55	31.9%
9	*Game shows*	48	27.9%
10	*Sports*	43	25.0%
11	*Food and drink television*	39	22.6%
12	*Travel television*	35	20.3%
13	*Current affairs, political talk shows*	28	16.2%
14	*Variety shows*	25	14.5%
15	*Reality television*	15	8.7%
16	*Religious television*	13	7.5%
17	*Telenovelas / soap operas*	4	2.3%

4.4 Perceptions of AR-TV

We asked participants to rate characteristics of AR-TV, *e.g.*, usefulness, desirability, fun, etc., by reporting their degree of agreement with several statements, *e.g.*, "AR-TV is informative," using 5-point Likert-scales; see the Study section for description of these measures and Figure 4 for results. The highest score was achieved by FUN with an average rating of 4.24 on a scale from 1 (*strongly disagree* that AR-TV is fun) to 5 (*strongly agree* that AR-TV is fun). Also, participants considered that AR is the "future" of television (average rating 3.98), probably because of AR being perceived highly INFORMATIVE (3.91), USEFUL (3.87), and with the capacity to mediate SOCIAL-INTERACTION (3.74). These perceptions led to a DESIRABILITY level for AR-TV above average (3.72). With respect to the DISCOMFORTING and COGNITIVE-EFFORT measures, results showed low mean ratings, *i.e.*, 2.38 and 2.58, respectively. Overall, these results show a positive perception of AR-TV.

4.5 Preferences for and Perceived Value of AR-TV

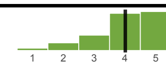
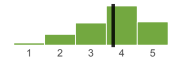
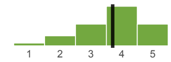
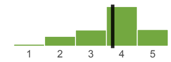
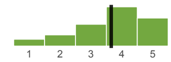
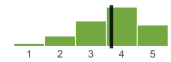
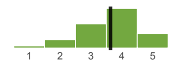
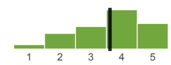
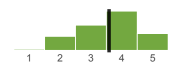
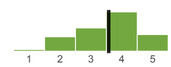
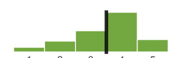
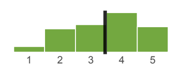
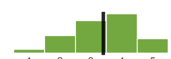
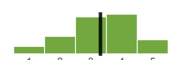
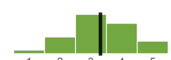
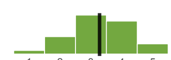
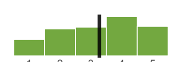
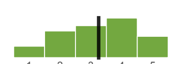
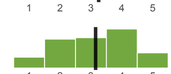
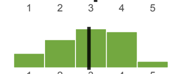
At the end of the questionnaire, we presented participants with 20 AR-TV scenarios (denoted in the following with the AR-SCENARIO independent variable), which participants rated using 5-point Likert scales, from *"1, not valuable"* to *"5, very valuable."* Table 5 lists all the scenarios and reports median ratings (*Mdn*, as the appropriate measure of location for ordinal data), but also mean values (M, useful to understand relative preferences for scenarios with equal median ratings), 20%-trimmed means ($M_{.20}$, recommended for non-normal data [59]), as well as the actual distributions of the preferences.

The scenario with the highest perceived value was interacting with AR content displayed around or in front of the TV set (Mdn=4.0, M=4.01, $M_{.20}$=4.22), which shows a strong interest for "lean forward" instead of "lean-back" consumption of TV content. The next highest rated scenario was displaying additional content, such as character names or details about the broadcast, right next to the TV (Mdn=4.00, M=3.72, $M_{.20}$=3.80). This result connects well with current practices of second-screen usage during television watching, also observed in our participants' responses, *i.e.*, 60.5% of our participants reported using smart devices *sometimes*, *very often*, or *always* when watching television. Scenarios involving video projections were also perceived valuable (Mdn=4.0, M=3.70, $M_{.20}$=3.82), being ranked in the 3rd and 4th places, respectively. Also, participants appreciated real objects coming out of the TV screen (Mdn=4.0, M=3.66, $M_{.20}$=3.85) significantly more valuable than real characters coming out of the TV (Mdn=4.00, M=3.46, $M_{.20}$ = 3.51, Wilcoxon signed rank test with continuity correction V=1163, p<.01). The scenarios with the least perceived value, nonetheless above *"3, moderately valuable,"* were having movie subtitles and other TV channels next or in front of the TV screen (ranked in the 19th and 20th places, respectively, V=1497.5, p<.01). A possible explanation for this result is that such scenarios would probably demand extra cognitive effort to perceive the additional content. In the support of this argument, we refer to a study by Vatavu and Mancaş [52], who found that more than three TV channels presented at once were difficult to follow by viewers. The AR-TV scenario regarding the display of live video or 3D representations of remote friends watching the same TV channel received a low rating as well (17th place, Mdn=3.0, M=3.27, $M_{.20}$=3.32), a result that correlates with the fact that the majority of our participants (87.8%) reported watching television alone.

To understand better the relationships between AR-SCENARIO and PERCEIVED-VALUE as well as any effects of AR-EXPERIENCE or TV-HOURS on the PERCEIVED-VALUE of AR-TVs, we ran a Brunner-Domhof-Langer's rank-based test[6] and generated scatter plots for these variables. The results showed a nonsignificant ef-

[6]Recommended by Wilcox [59, p. 554] for performing robust tests of significance for data that is not normally distributed. Implemented by the R function `bwrank(..)` from the "Rallfun" library available from Rand Wilcox's web page, `https://dornsife.usc.edu/labs/rwilcox/software/`.

Table 5. Perceived value of the 20 scenarios we imagined for AR-TV, which were rated by our participants with scores from *"1, not valuable"* to *"5, very valuable"* using 5-point Likert scales. *Notes:* medians (Mdn), means (M), 20%-trimmed means ($M_{.20}$), standard deviations (SD), as well as the distributions of preferences are reported to offer a complete perspective on the perceived value of our AR-TV scenarios; larger numbers denote more valuable scenarios.

	AR scenarios for television	Descriptive statistics for PERCEIVED-VALUE				
		Mdn	M	$M_{.20}$	SD	Distribution
1	I would like to be able to control and interact with AR content that is displayed around or in front of the TV set	4.00	4.01	4.22	1.03	
2	Additional content, such as character names or details about the transmission, displayed next to the TV set	4.00	3.72	3.80	1.02	
3	A very large field of view using video projections in the entire room	4.00	3.70	3.78	1.03	
4	A larger field of view created using video projections on the wall behind the TV set	4.00	3.70	3.78	0.99	
5	Real objects coming out of the TV set	4.00	3.66	3.82	1.16	
6	Different perspectives of the TV broadcast, such as a movie filmed from different angles, displayed next to the TV set	4.00	3.66	3.71	1.02	
7	User interface controls, such as capture snapshot or record video buttons, displayed next to the TV set	4.00	3.63	3.68	0.94	
8	TV channels displayed next to various physical objects in the room, such as weather channel next to the window, documentary channel next to the bookshelf, etc.	4.00	3.62	3.74	1.12	
9	Menus displayed next to the TV set	4.00	3.59	3.63	0.98	
10	Additional content, such as character names or details about the transmission, displayed in front of the TV set	4.00	3.58	3.64	1.00	
11	TV content displayed close to me so that I can touch it	4.00	3.50	3.64	1.05	
12	Real characters coming out of the TV set	4.00	3.46	3.51	1.16	
13	Links to other content, such as movies or photos, displayed around the TV set	3.50	3.40	3.50	1.02	
14	Additional content from my smartphone or tablet, such as contacts, notifications, or photos, displayed next to the TV	3.00	3.31	3.41	1.07	
15	Additional content, such as channel info or channel preview, displayed on top or around the TV remote control	3.00	3.31	3.37	1.00	
16	Additional information, such as description of buttons, displayed near the buttons of the TV remote control	3.00	3.28	3.36	0.98	
17	Live video or 3D representations of my friends, who are not in the same room with me, but who are watching the same TV show as I do	3.00	3.27	3.32	1.31	
18	Movie subtitles shown outside the TV set	3.00	3.25	3.29	1.20	
19	Multiple TV channels shown next to the TV set	3.00	3.15	3.19	1.17	
20	Multiple TV channels shown in front of the TV, between the viewer and the TV set	3.00	2.94	3.00	1.09	

fect of AR-EXPERIENCE ($F_{(2.581,40.687)}$=1.134, p=.342, *n.s.*), a significant effect of AR-SCENARIO ($F_{(15.525,\infty)} = 3.807$, p<.001), and a nonsignificant interaction between AR-EXPERIENCE × AR-SCENARIO ($F_{(26.439,\infty)}$=0.947, p=.541, *n.s.*) on the perceived value of AR-TV. Figure 5 illustrates visually the relationships between PERCEIVED-VALUE and TV-HOURS (left) as well as PERCEIVED-VALUE and AR-EXPERIENCE (right). Although a small increase in the average perceived value of AR-TV can be observed corresponding to an increase in the number of hours spent daily for watching television (Figure 5, left), the effect size of the linear relationship is very small ($R^2 = .01$). A similar result was found for AR-EXPERIENCE ($R^2 = .002$), showing little influence of the participants' previous experience with AR technology on what AR-TV scenarios they perceived valuable.

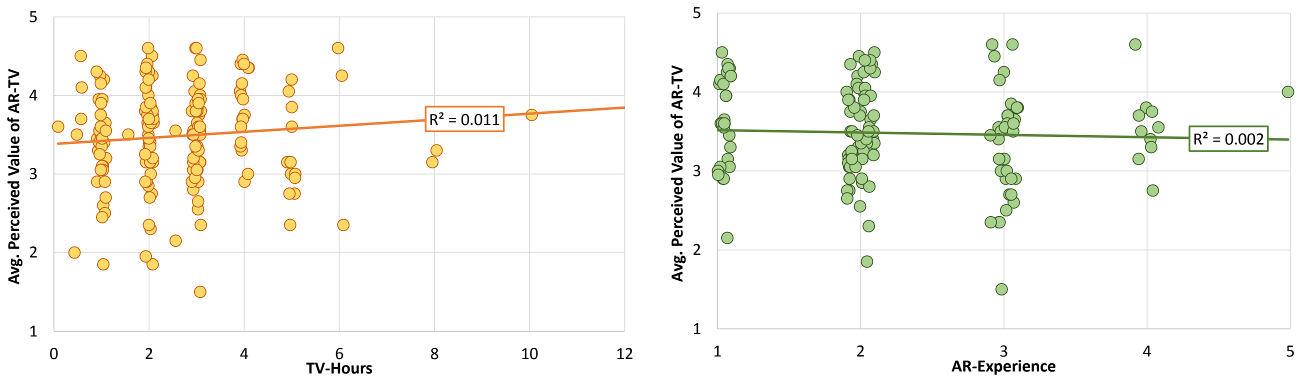


Figure 5. Relationships between TV-HOURS (left) and AR-EXPERIENCE (right) and the average PERCEIVED-VALUE of AR-TV scenarios. *Note:* a small jitter was added to the values of the variables shown on the *x* axis in both graphics to prevent overlapping between data points.

4.6 Summary

We found that AR-TV was perceived useful (3.87 average rating on a scale of 5), fun (4.24), desirable (3.72), informative (3.91), and with good opportunities to enable social interaction (3.74). A close look at our 20 distinct scenarios for AR-TV revealed respondents' preferences for interactive AR content displayed around, in front, and on the wall behind the TV screen as well as in the entire room. Regarding what to display, characters' names for movies, details about the broadcast, different perspectives or shooting angles, and menus and user interface controls were perceived useful to have by our participants. Overall, twelve of our twenty AR-TV scenarios (60%) received a median preference rating of 4 on the scale from 1 (*not valuable*) to 5 (*very valuable*). These results can be used to inform the implementation of AR-TV applications, and they also lead to opportunities for new investigations, which we discuss next.

5 Limitations

The results presented in this paper come from the first study conducted to collect users' preferences and expectations for AR-TV. Given this context, we preferred to run an *exploratory* study online to foster variety and large participation instead of, for example, a *hypotheses-oriented* examination of several AR-TV scenarios with a small focus group. While we acknowledge the inherent limitations of running online studies with participants that may be uncommitted or that drop out, the lack of experimental control, and problems caused by self-selection [37], our study can represent the basis for future work towards better understanding of users' preferences for AR-TV. This future work can be implemented in at least two directions: (i) cultural studies [24], where our study is replicated for respondents of diverse cultural backgrounds, such as from Asian, Arabic, European, South and North American countries; and (ii) by conducting focused, in-the-lab studies and presenting participants with actual prototypes for AR-TV and eliciting their feedback through participatory design [9, 23]. While the first direction of investigation might reveal an interesting effect of the cultural background on what are valuable AR-TV scenarios, the latter would enable precise control of technical aspects, such as photorealism or latency. We leave such interesting explorations for future work.

6 Conclusion

We reported in this paper results on users' perceptions of AR-TV by aggregating and analyzing the responses of the 172 participants of our online study. Our results show high perceived value for AR-TV scenarios involving interactive content, wall-sized and room-sized video projections, multiple perspectives of the same movie scene, and for objects coming out of the TV screen into the room. Other scenarios, such as live video of remote friends watching the same broadcast or multiple virtual channels displayed around the TV screen were rated as less valuable. Our work represents the first exploration of what users want and find valuable regarding AR-TV. We believe that more detailed investigations should follow in terms of a potential cultural effect on the perceived value of AR-TV and focused studies and evaluations involving actual AR-TV prototypes.

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