Reconsidering Registration: New Perspectives on Augmented Reality

Hanna Schraffenberger[1,2(✉)] and Edwin van der Heide[1]

[1] Media Technology, LIACS, Leiden University, Leiden, The Netherlands
h.schraffenberger@ru.nl, e.f.van.der.heide@liacs.leidenuniv.nl
[2] TiCC, Tilburg University, Tilburg, The Netherlands

Abstract. Augmented reality (AR) projects typically involve interactive systems that align virtual objects with the real world. This process is called registration and can make it seem as if virtual objects existed in the otherwise real environment. Registration is widely accepted as a defining and necessary characteristic of augmented reality. In this paper, we reconsider the need for registration on two levels. First of all, we argue that the intended presence of virtual objects in real space can be achieved without registration by an interactive AR system. Secondly, we suggest that the perceived spatial presence of virtual content in real space is not necessary for AR in the first place. We illustrate both points with examples and propose a more encompassing view of AR that focuses on relationships between the virtual and the real rather than on registration.

Keywords: Augmented reality · Registration
Virtual-real relationships · Theory · Information · Illusion · Presence
Mobile games · Sound art

1 Introduction

With the advent of augmented reality (AR), the presence of virtual content in real space has gained a new dimension. Virtual objects no longer simply appear on the screen of computers, tablets, mobile phones, smart watches, digital information boards, advertisement screens or other digital displays. Rather, they appear to exist right here, in our physical space, just like real objects do: Wearing a Head-mounted display (HMD), virtual, three-dimensional game characters appear to walk on real streets [1]. Looking at the environment through a mobile phone's screen, site-specific information, such as where to find nearby restaurants, metro stops and ATMs appears to be floating through the space in front of us [2]. More recently, Microsoft's HoloLens headset promises the possibility of building landscapes and filling our living rooms with virtual building blocks rather than physical lego bricks [3].

The presence of virtual content in real space that characterizes so many AR scenarios is typically simulated by an interactive system that aligns the virtual and the real and gives virtual objects a position in the real world. This process

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is called registration. A look at AR research reveals that registration is widely seen as a defining and necessary characteristic of AR (see, e.g., [4,5]). Most prominently, Azuma's [6] wide-spread survey describes AR in terms of interactive systems that not only combine the virtual and the real but also register (align) virtual and real objects with each other in 3D and in real-time. By now, this view of AR—and with it, the need for 3D registration by an interactive system—has been widely accepted (cf. [7]).

However, not everyone shares the view that registration is necessary. For instance, the call for papers of the 14th edition of the International Symposium on Mixed and Augmented Reality (ISMAR 2015)—the leading conference on AR—explicitly lists "augmented reality without 3D registration" as one of the two emerging areas of particular interest [8]. Furthermore, some researchers provide broader descriptions and definitions of AR. For instance, Manovich [9] suggests that "a typical AR system adds information that is directly related to the user's immediate physical space" (p. 225). Similarly, Klopfer and Squire [10] define AR in terms of "situation[s] in which a real world context is dynamically overlaid with coherent location or context sensitive virtual information" (p. 205). We, too, have argued that relationships between the virtual and the real characterize AR [11]. While these views suggest that the virtual has to relate to the real, they do not state that the information has to be *registered* with the real world in 3D.

In the light of these different views, we wonder what role registration plays in AR. Is it actually a prerequisite for AR—and if so, why? Could it be that we unnecessarily limit AR, if we only consider scenarios where an AR system registers virtual content with the real world in 3D? Is there a chance that other links between the virtual and the real, too, result in augmentation? In this paper, we address these questions and challenge the common understanding of AR in terms of interactive systems that align virtual and real objects in 3D.

The paper consists of five sections. In Sect. 2, we investigate the purpose of registration. This investigation reveals that registration is used to make it seem as if virtual objects were part of the otherwise real environment. It furthermore becomes clear that this effect is typically achieved by means of an interactive system that aligns the virtual and the real in 3D and in real-time. Subsequently, in Sect. 3, we show that this type of registration by an interactive AR system is not always necessary for virtual content to appear as part of real space. We illustrate this point with three examples. Following this (Sect. 4), we challenge the need for registration more fundamentally. We suggest that the (simulated) presence of virtual content in real space is not necessary for AR in the first place. We argue that virtual content can augment the real world in other ways and in particular, by informing us about the real world. Two examples demonstrate this point. Finally, in Sect. 5, we discuss our findings and propose a broader understanding of AR that focuses on relationships between the virtual and the real that participants experience rather than on the registration of the virtual and the real by an AR system.

We limit our discussion to visually and auditory augmented reality because the need for registration primarily surfaces in this area. Whereas registration is commonly approached from an engineering perspective, we approach the topic from a conceptual and experience-focused perspective. Technological questions, such as how to best implement or improve registration fall out of the scope of this paper. The paper reflects on existing projects from the domains of art, gaming and augmented reality. It aims to advance AR theory and practice through a better understanding of what AR is and potentially can be. As such, it does not present new empirical results.

2 The Apparent Presence of Virtual Objects in Real Space

There are many ways to present virtual content in the real world. For instance, virtual content can be displayed on a computer screen, projected onto a wall, broadcasted on loudspeakers or played back on head-phones. However, according to the prevailing opinion, merely displaying or presenting virtual content in the real environment does not suffice in order to create AR. Instead, researchers argue that virtual content has to be registered with the real world or aligned with real objects in 3D. So what is registration, why is it regarded necessary—what purpose does it serve?

Strictly speaking, opinions on what registration entails vary slightly. However, registration generally refers to the process of giving virtual objects a position in real space. For instance, Azuma et al. [4] uses the term to refer to the alignment of virtual and real objects with respect to each other and Drascic and Milgram [12] use registration to refer to the alignment of "the coordinate system of the virtual world with that of the real world" (p. 129).

The challenge of properly aligning the virtual and the real is commonly referred to as "the registration problem" and regarded one of the key issues in AR research (e.g., [5,6]). How this problem is addressed differs from project to project. However, registration is generally realized by an interactive computer system that aligns the virtual additions with the real world in real-time and in three dimensions (e.g., [6]). In the following, we refer to this form of real-time 3D registration by an interactive system as *registration in the traditional sense.*

Judging from AR literature, registration is such a prominent issue in AR, because it can create the illusion of virtual objects being part of and existing in the real environment. This is one of the primary goals in existing AR research [6,13]. According to existing research, registration not only serves the illusion of virtual objects existing in real space but is *necessary* for it. For instance, Azuma [6] writes: "[t]he objects in the real and virtual worlds must be properly aligned with respect to each other, or the illusion that the two worlds coexist will be compromised" (p. 367). Similarly, Vallino and Brown [14] point out "[t]o maintain the illusion that the virtual objects are indeed part of the real world requires a consistent registration of these two images–the major challenge for augmented reality systems" (p. 195). Likewise, Bajura and Neumann [15] write:

"Accurate visual registration between real and computer-generated objects in combined images is critically important for conveying the perception that both types of object occupy the same 3-dimensional (3D) space" (p. 52).

To some degree, practical AR projects seem to back up these concerns. A popular example of a mobile game, which does not properly register virtual content in real space is Pokémon Go. This game takes place in the real world, where players can use their phone to chase and capture so-called Pokémon (animal-like creatures). In the AR view of this game, virtual Pokémons are displayed on the mobile's screen, superimposed on a player's live view of the environment.

The application makes use of GPS coordinates and the phone's compass and gyroscope in order to include the Pokémon and other game-related content in the otherwise real environment [16,17]. This approach of placing virtual content in the real world suffers from several weaknesses: First of all, it has poor accuracy [18]. Furthermore, because the camera image is not analyzed, the application has no knowledge about spatial structure of the physical environment. In the case of Pokémon Go, these drawbacks can cause Pokémons to appear in unrealistic positions in the environment or can make them look like an independent overlay that floats on top of the camera feed, rather than as part of the environment. This can be seen in the first two images in Fig. 1. As these images show, inaccurate alignment of the virtual and the real indeed can hurt the perceptual illusion of virtual Pokémon existing at a position in the real environment.

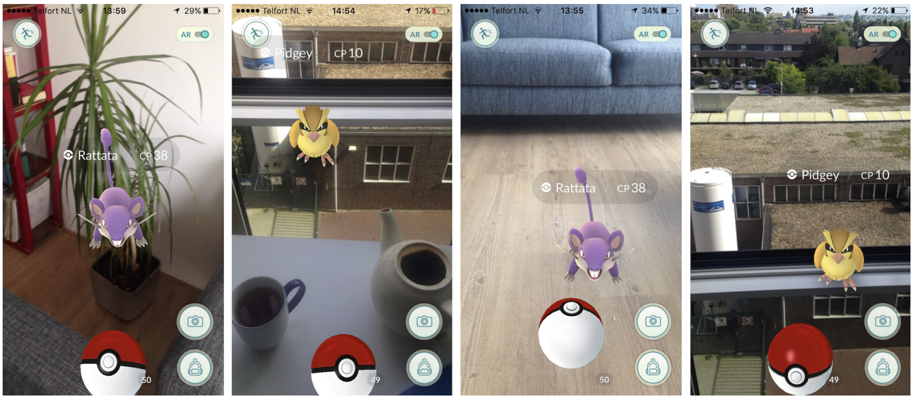

Fig. 1. At times, Pokémon appear at unrealistic positions and on top of the real world (images on the left). At other times, the virtual creatures appear to be part of the real environment (images on the right).

However, such issues are usually temporary. Despite the rather low accuracy, the virtual creatures regularly appear to be present in our real environment. We can see screenshots of such cases where virtual Pokémon seem to be a part of the real world in the two images on the right in Fig. 1.[1]

On first sight, the Pokémon Go example seems to support the reviewed claims that accurate registration is necessary for virtual objects to appear in real space.[2] However, poor registration has not prevented Pokémon Go from becoming one of the most popular mobile games so far [19]. The success of the game suggests that players seem to enjoy the game despite improper registration. This gives us reasons to believe that worthwhile AR experiences can be created without accurate registration.[3] Judging from the personal experience of the authors, we accept the virtual Pokémon as a believable part of real space even if they do not appear properly aligned. In fact, it even can be a fun aspect of the game, to actively move the phone around in order to manually align the displayed Pokémon with the environment and make them blend in with the real world. In any case, the example of Pokémon Go suggests that accurate and stable registration in 3D space is not always necessary. It raises the question whether AR applications have to 'fool' us perceptually in order to create the experience of virtual objects being part of the real environment. It furthermore suggests that the participant can play a more active role in aligning the virtual and the real, e.g., by moving the phone until the creatures seem to fit with the environment. We will explore this possibility further in the next section.

3 Alternative Approaches to Placing Virtual Content in Real Space

There is no doubt that interactive AR systems that align virtual and real content in 3D can make it seem as if virtual objects were part of real space. However, we wonder whether there are other ways of placing virtual content in the real world. In the following, we discuss three examples that suggest that this is possible. Next to visually augmented reality we will also consider sound-based forms of AR. After all, the concept of registration is closely tied to the idea of visual augmentations. Additional possibilities for integrating virtual content into the real world might exist when dealing with non-visual virtual content.

Forest walk. Early examples of AR experiences that are created without registration by an interactive system include Cardiff's audio walks [20], such as *Forest walk*. The artist provides participants with prerecorded soundscapes that are played back on traditional CD players or iPods while on a predetermined walk

[1] The author has positioned the phone manually to make the Pokémon appear at realistic locations. However, similar situations regularly arise without such efforts.

[2] Of course, one example does not allow us to draw general conclusions.

[3] Players can also turn off the AR mode entirely. If players approach a Pokémon with AR mode switched off, the creature appears in a virtual environment, rather than overlaid onto the camera feed. However, Pokémon are still positioned on a virtual map of the actual surroundings and in this sense, placed in the real environment.

[20]. Listening to the recordings on headphones while navigating the otherwise real environment, the recorded sounds often appear to originate in the physical environment[4] and mix in with our real surroundings. How is this possible?

One crucial aspect that contributes to the spatial quality of Cardiff's recordings is the used recording technique. Cardiff's audio walks have been recorded with binaural audio. Binaural audio is a recording technique that captures the complete auditive experience—including the three-dimensional spatial information of the sounds. Another important aspect is that the audio mimics the environment in which it is played back to the listener. The artist explains that "[t]he virtual recorded soundscape has to mimic the real physical one in order to create a new world as a seamless combination of the two" [20]. In line with this, Cardiff has recorded the audio material in the same environment that the listener navigates during the walk. "Forest Walk", for instance, includes natural sounds of the forest, such as the sound of crows [21]. Because Cardiff makes use of binaural soundscapes that were recorded in the listener's actual environment, the virtual sounds appear to be a spatial part of the real environment, even though there is no interactive system that aligns them with the real world.

Does this mean we are dealing with AR without registration? Not necessarily. One could argue that Cardiff's walks make use of *a different* (and much looser) form of registration: the participant is told where to start the walk and press play, and the audio mix includes instructions that tell the participant where to go and where to look. Indirectly, the instructions determine the participant's position in and movement through the space, and consequently, also roughly determine where the virtual sound sources appear in space.

One potential reason why this loose alignment suffices is that the recorded sounds not necessarily have to appear at a specific position in the surrounding space. For instance, no exact 3D registration is necessary when dealing with flying elements such as crows, as it does not matter where exactly they appear in the environment.

Mozzies. Another application that makes virtual objects appear in real space without 3D registration is the early mobile game *Mozzies*. This game was installed on the Siemens SX1 cell phone that launched in 2003 [22]. The mobile application used to show flying mosquitoes, overlaid on the live image of the environment captured by the phone's camera. Players could shoot the virtual mosquitoes by moving the phone and pressing a button when aiming correctly [23]. In contrast to Cardiff's work, the game makes use of an interactive system. However, the application does not make use of registration in the traditional sense, but instead, 'only' uses the camera as a motion sensor [23] and applies 2D motion detection [24]. Yet, judging from the images that can be found of this (and similar) games online, it appears as if mosquitoes were flying through the space in front of the phone's lens.

[4] This claim was confirmed by Zev Tiefenbach, the studio manager of Cardiff/Miller, who in turn confirmed this with Janet Cardiff (personal communication).

Presumably, this works because mosquitoes (like the crows mentioned above) 'only' have to appear to be flying *somewhere* in the surrounding space rather than at an exact position. To achieve this, exact registration seems not to be necessary. However, because the creatures are not registered in 3D, is not possible to walk around the virtual insects and look at them from all directions and angles. Furthermore, the virtual mosquitoes can not disappear behind real objects. (The same constraints currently hold for Pokémon Go.)

NS KidsApp. A third example of AR without registration in the traditional sense is the NS KidsApp. This mobile application by the Dutch railway operator *Nederlandse Spoorwegen* (NS) is primarily aimed at children (and their parents), and it introduces a short story with the two characters *Oei* and *Knoei*.

There are several playful assignments for the player that allow them to make videos with Knoei appearing in the otherwise real environment. For instance, the player is asked to put the camera against the window and film the outside. As a result, one can see Knoei flying next to the train in a superman kind of fashion. Likewise, when filming another player, one can see Knoei hovering over a train chair, showing off his muscles to his neighbor (see Fig. 2).

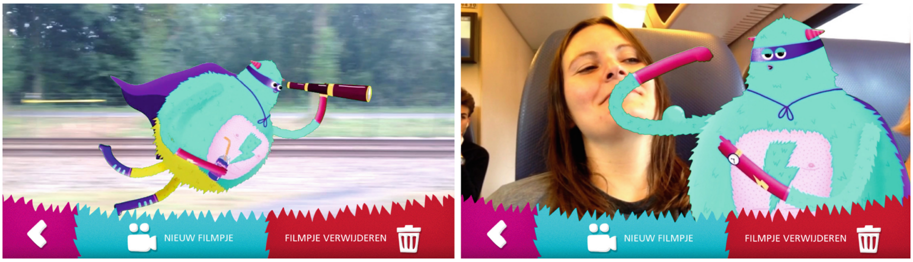

Fig. 2. The NS Kids app shows Knoei flying next to the train (left) as well as next to a player showing off his muscles (right) on the camera feed. Screenshots by Hanna Schraffenberger and Jurriaan Rot.

This application, too, creates the illusion of virtual content seemingly existing in real space, without the use of registration in the traditional sense. Like in Cardiff's case, instructions are part of the game. Here, they make sure that what the participant sees will serve as a fitting background for the virtual overlay.

4 Alternative Approaches to Augmented Reality

The previous section has revealed that the apparent presence of virtual content in real space does not always require registration by an interactive AR system. In this section, we challenge the need for registration more fundamentally and question whether virtual content has to appear as if it were spatially present in the real surroundings. Our idea is simple: Aside from registration, other links between the virtual and the real are possible. These potentially lead to other forms of AR. For instance, the virtual can inform us about our real surroundings. In our opinion, this can also augment the environment. We support this idea with two examples.

Audio Guides. The idea of virtual additions that inform us about the real world is common in the cultural sector. For instance, many museums provide additional information in the form of audio tours that guide the visitor through a museum, and which supplement the real world and ideally, enhance our experience of the exhibition. In our opinion, such audio tour guides can accompany a user and augment a user's experience of their real surroundings, even if they do not appear to be spatially present.

We are not alone with the opinion that audio tours and audio guides can be considered AR. For instance, Bederson [25] argues "[o]ne place a low-tech version of augmented reality has long been in the marketplace is museums. It is quite common for museums to rent audio-tape tour guides that viewers carry around with them as they tour the exhibits" (p. 210). Furthermore, Rozier [26], refers to audio tours as "perhaps the earliest form of 'augmented reality"' (p. 20).

Whereas audio guides typically provide factual information about the real surroundings, other possibilities exist. For instance, the artist Willem de Ridder has realized an audio tour in the "Stedelijk Museum" in Amsterdam in 1997 that told visitors about the meaning of 'invisible' elements in the museum [27]. This shows that the virtual information can relate the surroundings more freely.

Google Glass. The concept of using a virtual layer of information to enhance our everyday lives is also at the basis of the Google Glass project. Google Glass is essentially a head-mounted display in the shape of eyeglasses. A small display in one corner presents additional information (such as text and/or images) as an overlay on top of a user's view of the world.

The information displayed by Google Glass can be completely unrelated to a user's context (e.g., a random text message from a friend) but it can also relate to the user's real surroundings. For instance, the device can be used to translate advertisements and overlay driving instructions onto a user's view.

The role of Google Glass in AR is controversial. As we know, 3D registration is commonly considered necessary. This view excludes all Google Glass applications from the realm of AR. However, the 2015 call for papers of the leading AR conference ISMAR suggests Google Glass as an example of "augmented reality without 3D registration" and argues that "[l]ightweight eyewear such as Google Glass can be used for augmenting and supporting our daily lives even without 3D registration of virtual objects" [8]. In line with this, some researchers consider head-mounted displays like Google Glass in the context of augmented reality. For instance, Liberati and Nagataki [28] consider Google Glass an AR device, and distinguish among two types of current and future AR glasses: (1) AR glasses that inform the user about their surroundings and provide "informational text" to the user and (2) AR glasses that present additional objects, that are embedded in the real world and that potentially can interact with the real world as if they existed physically.

We, too, believe that virtual information can modify (our perception of) real objects. Arguably, it can add to and affect our experience of the real world and in this sense become part of and augment the environment. However, we believe such augmentations are possible independently of how the virtual information is presented. In other words, information can augment our surroundings no matter whether it is, e.g., overlaid with AR glasses, displayed on a phone's screen or delivered by a recorded voice on headphones.[5]

5 Discussion and Conclusion

Is registration necessary for AR? This question remains (to some degree) a choice. Definitions are not set in stone. It is up to us—the AR research community—to define AR and draw the lines on the emerging AR landscape.

There is no doubt that registration in the traditional sense plays a crucial role in AR. It is at the heart of almost all AR applications. Registration can make it seem as if virtual objects were present in the real space. In many contexts, such as in the medical domain or in a manufacturing setting, the need to accurately align virtual information with the real world is self-evident. Yet, we believe that by defining AR in terms of interactive systems that register the virtual and the real interactively, in real time and in 3D [6], we unnecessarily limit AR.

We have identified two main reasons to adopt a broader understanding of AR: First, the apparent presence of virtual content in real space, which seems to motivate the need for registration, also can be achieved *without* 3D registration by an AR system in the traditional sense. For instance, the participant can align the virtual and the real by moving in space until the right perspective is obtained. Also, many settings require less strict forms of registration. E.g., an exact alignment might not be necessary when dealing with flying objects. Second and more fundamentally, not all forms of AR require the spatial presence of virtual objects in real space in the first place. In particular, virtual content can inform us about the real world, and by doing so supplement and augment (our experience of) the real world. For instance, virtual museum guides do not have to look or sound as if they were spatially present in order to accompany our visit and affect our experience with their words. We see such scenarios as a form of AR that is based on the content-based relationship between the virtual and the real. We thus conclude that registration in the traditional sense plays a key role in AR, but is not necessary for AR per se. This raises one final question: If real-time registration by an interactive system in 3D is no defining factor, what then does define AR?

Strikingly, all encountered AR scenarios have one characteristic in common: *virtual content is experienced in relation to the real world.* In some cases, the link

[5] In many ways, information defies the terms virtual and real. Arguably, information can have the same effects, no matter whether it is presented virtually or physically.

between the virtual and the real is primarily spatial. For instance, the mosquitoes in *Mozzies*, the character Knoei in the *NS KidsApp* as well as the sounds in Cardiff's *Forest walk* all seem spatially present in the real surroundings. In other cases, the participant experiences a relationship between the virtual and the real on the content-level. For instance, the information provided by an audio guide typically relates to a physical artifact content-wise and consequently, is also experienced in relation to this artifact. Similarly, navigation instructions, such as provided by Google Glass and other mobile devices, relate to a participant's environment and are normally interpreted in relation to the real surrounding space. In line with these examples, we see AR environments as spaces in which the participant experiences a relationship between the virtual content and their real surroundings.

In contrast to common notions, our view focuses on the relationships between the virtual and the real rather than on registration and on the experience of the participant rather than on enabling technologies. Taking the participants' experiences into account is important because AR systems typically aim at providing the participant with an augmented experience of their environment. Instead of defining the field in terms of technologies that create such scenarios, we suggest defining the field in terms of the environments and experience we actually want to create. This will allow us to study the actual area of interest, even if enabling technologies change or take unforeseen form (such as in the case of Cardiff's audio walks).

Our view of AR is much broader than the common understanding of AR in terms of interactive systems that align the virtual and the real interactively, in real-time and in 3D [6]. Yet, it allows us to distinguish AR from other environments that include both virtual and real content. In particular, it sets AR apart from scenarios where the virtual and the real merely coexist in the same space and where both are experienced as *independent* from each other. For instance, our definition does not include scenarios where participants are immersed in virtual worlds and where they experience virtual elements as independent from their actual, real environment. Likewise, it does not comprise situations where a participant listens to an audio book and experiences this story as independent from and unrelated to their actual environment.

Our understanding of AR is not new—we have proposed the same view in previous publications (e.g., [11]). Furthermore, the above-reviewed definitions by Manovich [9] and Klopfer and Squire [10] also focus on the relationship between the virtual and the real. However, our paper sets itself apart from such earlier publications because it provides a detailed rationale for deviating from commonly accepted views of AR. Furthermore, our proposed definition differs from views such as put forward by Manovich [9] and Klopfer and Squire [10] with its focus on the participant's *experience*.

Our investigation reveals two main forms of AR: First, cases where a participant experiences the presence of virtual content in the real environment. We propose calling this "presence-based AR". Second, cases where the virtual augments the real on a content-level. We suggest calling this "content-based AR".

In future research, it would be desirable to explore if yet different forms of AR exist. For instance, can the virtual become part of the real world similarly to how a soundtrack becomes (a non-spatial) part of a movie? More generally, we would like to systematically explore what factors contribute to the experience of virtual content being part of the real space. We can imagine that next to registration, aspects such as the participants' imagination and an underlying narrative can play a major role in AR.

Our view of AR suggests that when it comes to creating AR scenarios, we have to consider and give form to the relationships between the virtual and the real. However, we have to keep in mind that establishing a relationship between the virtual and the real not automatically ensures that a participant also experiences this relationship. What is more, a participant might experience relationships that have never been created or intended. For instance, a museum visitor might listen to a virtual museum guide, but associate the information with the wrong artwork. Similarly, the same scenario might be experienced as AR by one person but not by another. In our opinion, the question whether a scenario should be considered AR can not be answered based on what a system does or displays. Instead, it remains a question of personal experience.

The main contribution of this paper is that it provides a better understanding of what AR is and potentially can be. It shows that aside from using traditional AR systems, alternative approaches to placing virtual content in real space exist. Furthermore, it shows that aside from making virtual objects appear in real space, alternative approaches to creating AR experiences exist. In addition, our paper complements technology-focused AR research with its focus on the participant's experience.

Our investigation has revealed various examples of interactive applications that defy existing definitions of AR but yet, augment our experience of our physical surroundings. This shows that narrow definitions not necessarily prevent practitioners to think outside of the box and to come up with different forms of (arguably) augmented reality. Yet, we expect that a better and broader understanding of AR will highlight those possibilities and hopefully, inspire even more and new forms of AR.

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