Arguably augmented reality : relationships between the virtual and the real

Schraffenberger, H.K.

Part III

Conclusion

7 Conclusion

In the last seven chapters, we have addressed the nature and possible manifestations of augmented reality. We have explored AR both theoretically as well as practically and we have applied an unconventionally broad perspective. The investigation has led to various new insights. In this final chapter, we summarize our main results and reflect on our findings. We revisit some of the questions that have surfaced during this trajectory and that we can answer now, after having had a critical look at existing research and after having worked with AR ourselves. Furthermore, we present suggestions for designing AR environments as well as possible directions for future AR research.

7.1 What Is Augmented Reality?

One of the main goals of this thesis was to understand the nature of AR and to answer the question what augmented reality is. So, what is augmented reality? In our opinion, AR is an environment in which a participant experiences a relationship between the virtual and the real. More specifically, AR is concerned with relationships between the virtual and the real physical environment. Since real environments are multimodal by nature, AR environments are also multimodal, even when the virtual content is only mediated by one modality. The relationships between the virtual and the real set AR apart from those environments where the virtual and the real merely coexist and where both are experienced as independent from one another.

In the following, we apply this definition to questions that have surfaced throughout this thesis. We place our view of AR in the context of existing research and emphasize differences. This will illustrate how our understanding of AR differs from common notions in three ways.

7.1.1 From Technologies to Experiences

One of the most prominent understandings of AR in existing research is the idea of AR as a technology. But is AR a technology? According to our definition, the answer is no. Although we believe that technologies enable AR, we do not treat AR as a technology. In our opinion, a reason to change towards a more environment- and experience-focused view is that the ultimate purpose of AR technologies is to allow people

to experience virtual content in relation to an otherwise real environment. If we ultimately aim at creating certain environments and experiences, why define the field in terms of the technologies that enable them rather than in terms of the environments and experiences we are interested in? An environment- and experience- focused definition will hold, even if enabling technologies change or take unforeseen forms.

If one accepts that AR is characterized by the experience of virtual content in relation to the real world, a definition in terms of enabling technologies becomes unfeasible. For one, there is no one single kind of technology that creates such experiences. To mention just a few examples, we have seen projects where a participant listens to prerecorded audio on a simple mobile CD player. Likewise, we have seen setups that allow a participant to see virtual content in real space with a head-mounted display and projection-based setups that present virtual content in the real environment directly. In addition, we have encountered devices that use electric current to change a food's taste or the tactile feeling of a real object. In our opinion, the main thing these various technologies have in common is the experience they evoke.

Furthermore, the same type of technologies can be used for characteristic AR experiences as well as for other purposes. For instance, a CD player can be used to listen to audio walks where virtual sounds mix in with the real environment. However, one can also use it to listen to music and to isolate oneself from the real surroundings. Likewise, we might use a projector to present a movie on a wall, but we can just as well use it to project a slowly expanding crack onto the wall that looks as if actually existed in the real environment. As this shows, the technology alone does not determine whether we are dealing with AR experiences or not.

7.1.2 From Vision to Multimodal Environments

Existing understandings of AR are often focused on what a user or participant *sees*. Accordingly, AR is commonly understood in terms of virtual *imagery* that is overlaid onto a user's or participant's *view* of the world. In contrast, our definition of AR suggests that we have to approach AR from a multimodal and all senses-encompassing point of view. We have identified many reasons for this. First of all, we believe that a participant experiences virtual content in relation to the physical world. This physical world is multimodal. As such, the resulting environment entails both virtual as well as multimodal real elements. As briefly mentioned in section 7.1, AR is inherently multimodal because an AR environment includes the multimodal real environment. Aside from this, our definition leaves room for virtual content to take on non-visual and also multimodal forms. In our opinion, there is no good reason to exclude such virtual content from the domain of AR.

Even if one disagrees with our notion—and defines AR in terms of visual overlays—it makes sense to treat AR from a multimodal perspective. This is because also solely visual additions can affect our non-visual impressions of the world. For instance, we have encountered a project where the visual information changes how real objects feel. If we solely focus on what a participant sees, we might affect a person's non-visual experience of the world without being aware of this. We believe that the combination of these arguments makes a compelling case to treat AR in a senses-encompassing way.

7.1.3 From Registration to Relationships

Many AR scenarios are realized by means of an interactive system that aligns virtual and real elements in 3D. If we are to believe general opinions and widespread definitions, this alignment or registration process is necessary for AR. In contrast, our definition does not require registration. Instead, it focuses on relationships between the virtual and the real. Registration can be such a relationship but other possibilities exist as well.

There is no doubt that spatial links between the virtual and the real are at the heart of many AR applications. However, our main argument to define AR in broader terms is that other types of relationships also lead to the augmentation of the physical world. Most notably, the virtual can relate to the real world on a content-level, and e.g., affect our experience of the environment by informing us about our surroundings.

One might disagree with this opinion. However, even if one approaches AR in terms of interactive systems that spatially align virtual and real content in 3D, it still makes sense to look beyond *spatial* registration. This is because such interactive systems typically aim at making it seem as if virtual content existed in the real environment. This goal, however, is not only a matter of spatial alignment. Many other relationships between the virtual and the real can potentially contribute to or harm this underlying goal. For instance, we can imagine that the presence of a virtual creature in the real environment is much more convincing if this creature listens and reacts to the sounds in the environment. At the same time, the illusion of it being present in the space might be harmed if the creature is not affected by real light sources or by real wind, if it is not reflected in real glossy surfaces or if it remains dry when it rains. If we look at current AR research, this idea is acknowledged, but primarily explored with respect to optical effects between the virtual and the real, such as illumination, reflections and shadows. Other types of relationships have still received little attention.

Arguably, a strength of this definition is that it is broader than most common views on AR. We hope this broader perspective will free prac-

titioners and researchers alike from restricting ideas, such as the association of AR with *visual* overlays, and thereby inspire and facilitate new and different forms of both AR and AR research. However, one might also argue that our definition is too broad. For instance, according to our definition, food with synthetic additives or the use of air fresheners in a real space could be considered examples of AR. Likely, few readers will agree with such a broad notion of AR. However, we believe that considering such extremes is important because it shows us how normal and commonplace synthesized information has become in our everyday lives already—possibly, we will be equally casual about the presence of virtual objects in real space in the future. On the other hand, we believe that for many purposes, a more narrow definition will better describe the actual focus of an AR project. In this respect, the many proposed subforms of AR (see section 7.2) can be used to describe AR projects more narrowly. [1]

[1] However, where necessary, our definition could also be refined by using a different definition of the virtual. E.g., defining the virtual in terms of computer-generated simulations would exclude examples such as the use of air fresheners and food additives, but likewise, exclude analog audio recordings.

Although we have reached a firm conclusion, our claims should not be taken as proven facts. The question of what AR is—to some degree—will always remain a matter of opinion. We have supported our opinion with arguments. Yet, many might disagree with our view of AR. This is not a problem. However, we hope to nonetheless convey that there is a family of environments in which participants experience relationships between the virtual and the real and that it makes sense to approach this collection of environments as a cohesive field. These points should hold, independently of whether the reader agrees to see this as part of the AR field or not.

7.2 *What Forms Can AR Take?*

A second question that has fueled our exploration is what forms AR can take. The answer to this question depends on the chosen perspective and point of interest. On a fundamental level, we have identified two forms of AR:

- **Presence-based AR**: Here, a participant experiences the presence of virtual content in the real environment. In other words, virtual content seemingly exists in real space, rather than, e.g., on a screen or in a separate virtual world.

- **Content-based AR:** In this form of AR, the virtual relates to the real environment content-wise. This is, e.g., the case when virtual content informs us about our real surroundings or when it tells a story about the real environment.

In both presence-based AR and content-based AR, virtual content is presented in and relates to a real physical environment.

Another way to distinguish between different forms of AR is based on how this virtual content affects its real surroundings. Based on the

role that the virtual content plays in the real environment, we distinguish between the following sub-forms of AR:

- **Extended reality:** Here, the virtual supplements the real. The environment appears to contain more/additional information.
- **Diminished reality:** In this case, the virtual removes the real elements from the perception of the participant. As a result, there seems to exist *less* content in the surroundings.
- **Altered reality:** In this form of AR, the virtual transforms the apparent qualities of the real world. For instance, the virtual might alter the perceived size or shape, weight or texture of real objects. As a consequence, the participant not necessarily perceives more or less information, but instead, perceives different information.
- **Hybrid reality:** Here, the virtual completes the real. It does not serve as 'something additional' and optional but rather is an integral part of an object or environment. A hybrid object/environment would be considered incomplete without the virtual component.
- **Extended perception:** In this case, the virtual translates already present and real but unperceivable aspects of the environment into virtual but perceivable information. As a result, the participant can perceive more aspects of the environment. For instance, a participant might be able to hear radioactive radiation. This form of AR differs from other manifestations because it is primarily concerned with augmenting a participant's perception rather than with augmenting the environment.

Finally, we can distinguish between two different manifestations of AR with respect to how the augmented environment compares to the real world:

- **Imitative augmented reality:** This form of AR mimics reality and, e.g., aims at presenting virtual objects that look and behave like real objects. The ultimate goal of much research in this context is to create AR environments that are indistinguishable from real environments.
- **Imaginative augmented reality:** This type of AR takes the form of new and imaginative environments that have no equivalent in a purely physical world. Research in this context explores the fact that virtual objects do not have to look, feel or behave like real objects.

It should be noted that the above-described forms of AR are neither exhaustive nor exclusive. The different forms can be combined. Even seemingly opposing forms can be united in one AR environment. E.g., an AR environment can mimic the real world when it comes to gravity but also allow virtual objects to move through real walls.

7.3 New Forms of AR

We have started out this trajectory with two main aims: First of all, advancing AR research through a better understanding of AR. Arguably, the above-summarized theory fulfills this goal and contributes to this end. In addition, we have set out to facilitate, create and explore new forms of AR. We have pursued this goal in two contexts.

7.3.1 Introducing New Laws

First of all, we have explored new forms AR with respect to influences between the virtual and the real. Here, we have shown that AR does not have to adhere to physical laws. Instead, we can introduce new laws. Of course, this does not mean that we can make real objects float through space or allow people to walk through physical walls—real elements still follow the laws of our physical world. However, virtual objects can behave differently, and react to the real world in new and imaginative ways. We have demonstrated this by introducing imaginative attractive forces. For instance, we have created an environment where virtual objects are attracted by real objects of a similar color or by light. We see a lot of potential in realizing imaginative influences between the virtual and the real and hope to explore this research direction further in the future.

7.3.2 Introducing New Objects

A second way in which we have explored new forms of AR is by designing a novel kind of virtual object, namely the so-called sonically tangible cube. As we see it, sonically tangible objects do not look, feel or behave like any real object, and they are also perceived differently from how we perceive real objects. Sonically tangible objects can appear to exist in real space, but unlike real objects, they are invisible and non-tactile. The underlying concept is that 'touching' such a virtual object triggers binaural sounds that originate from the exact spot where the object is touched. Our initial experimentation has suggested that this sound-based approach can convey the presence of virtual objects in real space and result in almost-tactile experiences. We believe that when it comes to creating new forms of AR, a main direction to pursue is working with new types of virtual content that does not try to mimic real objects.

In our opinion, the combination of our practical and theoretical exploration reveals many concrete insights into what AR is and what else it potentially can be.

7.4 Pending Questions

Our review of existing AR literature (chapter 2) has raised questions that we can answer now—by applying our definition and by looking back at the preceding chapters. For instance, we have seen that little consensus exists on what is augmented in AR. In accordance with our proposed definition, we suggest that the virtual augments that to which it relates. More importantly, the virtual and the real relate to, add to and augment one another. During this trajectory, we have, among others, encountered scenarios where the virtual augments a specific physical object, where the virtual augments the general environment, where virtual content augments humans and where it augments media content presented in books or music playing on the radio.

Another question that has surfaced in the beginning and that we can answer now concerns the role of the participant. Do we have to be present in an augmented environment to experience AR? Is AR something, we can watch on television or is it something we have to interact with and engage with more actively? According to our definition, AR results from experiencing relationships between one's real surroundings and virtual content in this environment. This entails that the participant is part of the environment. However, just like we can experience some aspects of a physical environment in a mediated form, we might also be able to experience some aspects of augmented reality in a mediated form—for instance, when watching a video of someone else's AR experience online.

7.5 Limitations and Concerns

This thesis focuses on the conceptual characteristics and possibilities of AR. In contrast, technological issues, such as how to technically implement AR or advance AR systems, fall out of the scope of this thesis. Although we have addressed AR both in depth as well as in breadth, our research has some limitations.

With respect to methodology, one limitation is that our practical observations and propositions are based on our own, subjective experiences. For instance, we have assessed that virtual objects do not have to behave like real objects in order to appear as a believable part of real space. Likewise, we have concluded that sonically tangible objects create an almost tactile-like and new experience. However, these propositions are largely based on our own experience. Naturally, our own experiences might have been biased. We cannot rule out that our initial expectations and intentions have contributed to our resulting experience. Furthermore, people are different and our own experience might not represent how other participants perceive AR. These issues are especially relevant because we have argued that AR is the result of the *experienced* relationships between the virtual and the real. It hence

would be very desirable to study how others experience our proposed AR scenarios.

Another limitation concerns the technological implementations. So far, most of our projects have been realized with rather cheap equipment in a controlled office environment. Furthermore, we have limited the complexity of all projects by determining one fixed point of view from which the augmented environment can be perceived. Although we have shown that several concepts are feasible in this specific context, it remains open whether similar ideas can be implemented in real-world settings that are not as predictable and that poses additional challenges, such as a moving participant.

When it comes to our theoretical approach, a concern is that we have made inferences about AR experiences from studying textual or visual descriptions of AR research projects. Unfortunately, such descriptions often focus on other aspects, such as the technological workings of an AR system. Hence, our assumptions about the resulting experiences might not always be correct.

Like every printed publication about AR, our thesis faces the challenge of describing a fast-moving field. There is no way to prevent this: by the time this thesis reaches the reader, AR technology will have advanced and additional relevant publications will have appeared. However, it is also great to see that since originally submitting this thesis and finalizing it, more experience-focused and modalities-encompassing views have emerged. For instance, the recent book "Augmented Human" by Papagiannis (2017) shares our multimodal approach to AR and—like this thesis—looks beyond the mere technological aspects of AR.

In this thesis, we have challenged many prevailing views and opinions about AR, such as the idea that AR overlays virtual imagery onto a user's view. It should be noted that many of the reviewed claims have been presented in the context of a specific AR project and with no aspiration of describing AR in a more general sense. While we have challenged such views on a general level, we do not mean to critique them on an individual level. E.g., the claim that AR technology overlays virtual images onto a user's view makes sense in the context of a project that works with such a technology. It is only natural that many authors only describe what is relevant to their project, rather than the general field of AR. With respect to this, we believe this thesis fills a gap: we are not aware of any AR publication that presents such a comprehensive overview of the general field.

It stands out that many of our conclusions mirror our point of departure. For instance, we have approached AR with the idea that it engages all human senses and subsequently, have arrived at the exact same conclusion. Of course, this raises the concern of circular reasoning—have we arrived at our conclusions because we have been assuming them all along? In our opinion, this is not the case. Rather,

we have explored what AR entails if we apply a broader view. In our opinion, this exploration has revealed a complex but coherent image of the AR landscape that reaffirms the value of our chosen perspective. Hence, we conclude that our point of view does make sense. This, however, does not mean that it is the only valid view. We believe the contrary is the case: our perspective on AR can complement rather than replace existing notions.

7.6 Creating AR

AR is not only a research field but also of interest to artists, designers and developers. When it comes to creating AR experiences, we have arrived at some insights that can guide and inform design processes. We will quickly summarize these points:

- Creating AR experiences concerns more than designing virtual content for the real world. Namely, it involves the design of the relationships between the virtual and the real.
- The physical component/environment does not have to be taken for what it is. It can be (re-)designed as well.
- AR environments are not something we see but something we experience with all our senses. Virtual content can take non-visual and multimodal forms and react to non-visual properties of the real world.
- AR environments are not something we consume rather passively, like watching a movie. Instead, they are environments we interact with. AR environments should be designed to facilitate action in and interaction with the environment.
- AR does not have to mimic reality. We can create new forms of environments, introduce new laws and create virtual objects that do not imitate real objects.

To summarize, designers can give shape to the virtual, the real, as well as to the relationship between the two. We hope that a better theoretical understanding of AR will inform AR practice and development and lead to new and exciting AR works.[2]

7.7 The Future of AR and AR Research

Our investigation of AR has raised many issues that could be addressed in the future. First and foremost, it would be desirable to conduct empirical studies with unbiased participants. Such experiments could not only be used to validate our findings but also to obtain new insights into AR experiences. In our opinion, it would be particularly

[2] In this thesis, we have identified various examples of interactive applications that defy prevailing 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.

interesting to address the perceptual goals of AR with empirical studies. For instance, AR often aims at making it seem as if virtual objects existed in the real environment. We believe that future research could more consistently measure whether this goal is met. Furthermore, it should systematically explore which factors contribute to the experience of virtual objects existing in real space. For instance, does it harm our experience if virtual objects are not reflected in real-world objects? Does it benefit our experience if virtual creatures react to sounds in the environment? A first step towards this goal will be to develop and adopt methods that can measure the presence of virtual objects in the real environment. While VR research has established and widely adopted questionnaires to measure a participant's presence in a virtual environment (see, e.g., Witmer and Singer, 1998), AR research—to the best of the author's knowledge—does not (yet) have similarly established and adopted methods to measure the perceived presence of a virtual object in real space.[3] Although the question whether virtual objects are experienced as present in real space differs substantially from the question whether participants feel present in a virtual environment, existing VR research on presence and telepresence (e.g., Sheridan (1992), Witmer and Singer (1998), Steuer (1992) and Schubert et al. (2001)), can serve as a point of departure for AR research into the presence of virtual content in real space. This is because many factors relevant for presence in VR might also be relevant for making objects appear as if they were present in the real world. For instance, interactivity and vividness (as proposed by Steuer (1992) in the context of VR) might also play a role in how present virtual content appears in real space.

[3] A questionnaire for measuring a virtual object's presence in the real world has been proposed by Regenbrecht and Schubert (2002). However, as of 12th February 2018, its adoption in AR research is quite low. To give an impression: According to Google Scholar, Witmer and Singer's paper that proposes a questionnaire to measures a user's presence in a virtual environment currently counts 3362 citations. In contrast, the AR presence questionnaire by Regenbrecht and Schubert (2002), which focuses on a virtual object's presence in the real world, currently has 19 citations.

Another issue that would benefit from an empirical study is the concept of believability. Virtual objects do not have to adhere to physical laws, and AR can take new and imaginative forms. However, not everything that can be realized technologically is also credible. It would be interesting to gain better insights into what forms of AR are accepted as believable, and what factors affect whether an environment is perceived as credible.

On a more general level, we believe future AR projects will benefit from establishing more influences and interactions between virtual content and the real world. First of all, such influences can potentially support the common goal of making it seem as if virtual objects existed in the real environment. Presumably, if a virtual object reacts to a physical object, this can heighten the impression that both objects exist in the same space. What is more, influences between the virtual and the real can facilitate the often-desired interaction between a participant and virtual content: If the virtual reacts to the real world, a participant can interact with virtual objects by interacting with the real world. For instance, in one of our projects, a participant can move real colored objects and thereby, play with virtual colored objects.

Furthermore, future projects can benefit from incorporating both multimodal virtual content as well as taking multimodal qualities of the real world into account. This thesis has sketched out ideas that are just waiting to be realized, such as virtual leaves that fly in real wind and virtual creatures that can be lured closer by making sound. In line with this, we believe future projects can take up the idea that virtual elements can sense the world as well as act in and react to the world.

Whereas much AR research and development mimics our physical reality, we believe much potential lies in imaginative forms of augmented reality. If we imitate a real environment, we know in advance how the result will turn out if we succeed. If we try to create something that does not yet exist, the outcome is uncertain and might surprise us. In his vision about the ultimate display (a room in which a computer controls the existence of matter), the "father of computer graphics" Sutherland concludes that an ultimate display "could literally be the Wonderland into which Alice walked" (p. 2). Augmented reality is no ultimate display. Yet, is has the power to transform our everyday reality into a wonderland. We have shown that AR can use new laws, introduce new types of objects into this world and consequently, facilitate new kinds of experiences. In L. Carroll's wonderland, Alice experiences herself grow enormously after eating a magical cake. Consequently, she is so surprised that she momentarily forgets how to speak proper English and exclaims: "Curious and curiouser!" (L. Carroll, 2015, p. 13). As an AR community, let us go down the rabbit hole and make sure things get curious and curiouser!