Sensor-supported Game Mechanisms for Augmented Reality

Bachelor Thesis
Submitted in Fulfillment of the Requirements for the Degree of
Bachelor of Science in Game Design

Felix Emmerich
Registration Number: 204101324

Examiners: Prof. Dr. Roland Klemke
Thomas Hummes

Abstract

This paper provides an overview of Augmented Reality definitions, approaches and applications, as well as sensors and design patterns, generally and in regard to gaming applications. Based on this research, the author developed a number of design patterns for sensor-supported Augmented Reality games and exemplarily adapted a sample of them as game mechanisms in the Unity game engine for use with the Microsoft HoloLens.

Table of Contents

1 Background

1.1 Introduction

Augmented Reality (AR) is bigger than ever before. The recent success of the game *Pokémon GO*, coupled with advancements in the related domain of Virtual Reality, has spurred popular interest in the combination of real and virtual content which has long been an area of academic interest. Microsoft's HoloLens, a Mixed Reality HMD (head-mounted display), a development version of which was released in 2016, shows great potential despite a currently high price point.

This thesis seeks to provide an introduction to relevant topics before discussing a framework for sensor-supported Augmented Reality games. First, definitions and approaches to Augmented Reality are presented with examples of existing applications in the fields of education and expertise transfer, industrial use, and video games, followed by a brief discussion on the potential and limitations of the medium. Afterwards, the paper goes into sensor technology and applications, with a special focus on video games, and finally design patterns. In the second half, the framework for sensor-supported Augmented Reality is conceived of and partially implemented in the Unity game engine for the Microsoft HoloLens.

The software implementation, in the form of a Unity project, as well as a Visual Studio solution for each example, can be found on the CD at the end of this paper.

1.2 Motivation

The present thesis is a continuation of the work the author performed during an internship at the Open University of the Netherlands, as part of the WEKIT project. WEKIT (Wearable Experience for Knowledge Intensive Training) is a European research project that aims to develop a new approach to expertise transfer by means of wearable technology, presented through task-sensitive Augmented Reality ("What is WEKIT?," n.d.). During this internship, the author was able to familiarize himself with topics such as Augmented Reality and the combination of various sensors.

A focus group survey (German, see appendix) was conducted in preparation for this paper, in order to ascertain whether there was demand for research into these topics and what should be the goal of such research. The 18 participants involved were current and former game design students, as well as one professor for game design. Game development expertise ranged from one year to four or more. The survey revealed interest, but inexperience in the usage and development of augmented reality applications; although all but one of the

participants knew the term Augmented Reality, only half of them reported having used AR applications before and only three out of the 18 participants had experience developing them. However 12 of the remaining 15 expressed interest in doing so. Despite this, the participants showed mixed (though generally positive) expectations of the field in regards to both the gaming industry in general and education in particular: When asked whether Augmented Reality games would be important in these domains in the future, both averaged a score of 3.388… on a Likert scale from 1 (disagreement) to 5 (agreement). Another question concerned whether they thought using additional sensor data could improve Augmented Reality applications, especially data relating to the user such as data on movement or body posture. The response was more uniformly positive, averaging a score of 4.388…, although some participants noted a lack of knowledge of sensor technology.

This combination of interest offset with lack of experience and skepticism towards the future suggested that an investigation into the prospects of augmented reality gaming and systematic guidelines towards the design of AR gaming applications could prove beneficial to current game design students.

1.3   Related Work

Fields of research that overlap with Augmented Reality include Virtual Reality, which puts the user into a completely virtual environment, or the broader term of Mixed Reality; ubiquitous and wearable computing, as well as the internet of things (see Mattern & Floerkemeier, 2010) all allow users to interact more broadly with their environments, to which ends a variety of sensors may be used.

According to Lamantia (2009) "the convergence of mobile computing and wearable computing with augmented reality is naturally of great interest to interaction designers who are interested in the rise of everyware" ("Augmented Reality: A Thumbnail Sketch" para. 2), while Papagiannakis, Singh, & Magnenat-Thalmann (2008) similarly refer to "the convergence of wearable computing, wireless networking and mobile AR interfaces" as bringing about "a new breed of computing called 'augmented ubiquitous computing'" (p. 1).

Some Augmented Reality Games may also be categorized as Pervasive Games, Location-based Games, or both, though the former does not require technology and the latter is primarily occupied with spatial characteristics (Wetzel, 2013, p. 1).

Pattern languages, as discussed in section 2.3, exist across a variety of fields, such as architecture and software engineering. In the case of e.g. the latter and Augmented Reality, there is also the more general field of Human-computer interaction (HCI).

2   Literature Review

This chapter comprises a summary of literature on the topics of Augmented Reality, sensors and design patterns. The content was first selected through online searches for possible areas of interest, such as the topics mentioned above, more specialized areas like AR visualization, related topics like the internet of things, and various combinations of all of the above. The author was also directed towards specific topics by the examiners of this paper. From there, the search shifted to references used in the above sources, and so on.

The chapter does not attempt to present a comprehensive overview of any of its topics, as doing so would be out of its scope. It does however cite papers that go more in-depth.

2.1   Augmented Reality

In 2011, the NMC Horizon Report stated that "Augmented reality, a capability that has been around for decades, is shifting from what was once seen as a gimmick to a bonafide game-changer" (L. Johnson, Smith, Willis, Levine, & Haywood, 2011, p. 16). Since then, the availability of Augmented Reality applications on consumer-grade devices such as smartphones has been driving the field forward, as referenced by researchers like Specht, Ternier, & Greller (2011, p. 117) and Munnerley et al. (2012), the latter of which stated that "the fact that these new layers can be accessed with consumer-level mobile devices means that they offer a uniquely open way to enrich environments and offer multiple, flexible learning opportunities" (p. 41).

The following sections will first present a number of definitions and taxonomies for Augmented Reality, before listing examples from the educational, entertainment and commercial sector.

2.1.1   Definitions and classifications. The term Augmented Reality was first used by researcher Tom Caudell in 1992, according to e.g. Olshannikova, Ometov, Koucheryavy, & Olsson (2015, p. 18); however there exist a multitude of definitions and the term has retroactively been applied to older work – such as "the head-up instrument displays and targeting devices airplane manufacturers created for military pilots shortly after World War II" (Lamantia, 2009, "Augmented Reality: A Thumbnail Sketch" para. 1).

A frequently cited general description of AR utilizes the Virtuality Continuum by Milgram & Kishino (1994), which places real environments on the left, virtual environment environments on the right, and Augmented Reality left from the center (under the umbrella term of *mixed reality*, which also includes *augmented virtuality*).
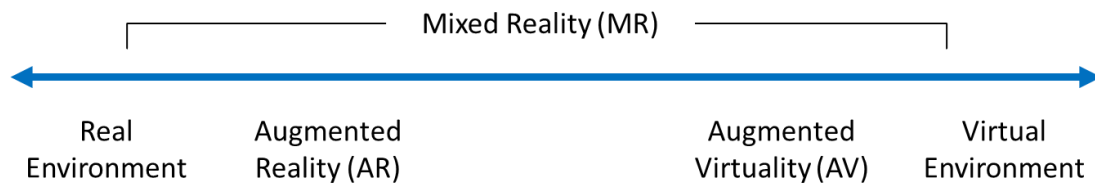
7

Figure 1: Virtuality Continuum. Adapted from "A Taxonomy of Mixed Reality Visual Displays," by P. Milgram and F. Kishino, 1994, IEICE Transactions on Information and Systems, 77(12).

Similarly, L. Johnson et al. (2011) refer to AR as "the addition of a computer-assisted contextual layer of information over the real world, creating a reality that is enhanced or augmented" (p. 16).

More detailed classifications show some differences. As FitzGerald et al. (2013) point out, early research focused on "the use of AR as a primarily graphical display" (p. 44). For example, Azuma (1997) defined Augmented Reality systems as "[combining] real and virtual . . . interactive in real time . . . registered in three dimensions" (p. 356).

However, over time definitions have undergone numerous changes. Just four years later, Azuma et al. (2001)instead listed the following qualifiers for an AR system: "Combines real and virtual objects in a real environment; runs interactively, and in real time; and registers (aligns) real and virtual objects with each other" (p. 34).

While both papers mention that Augmented Reality may apply to all senses, they only do so briefly. As the field advanced, applications including other senses became more commonplace and classifications were adjusted accordingly. For example, FitzGerald et al. (2013) include in their working definition of AR "the fusion of any digital information with physical world settings, i.e. being able to augment one's immediate surroundings with electronic data or information, in a variety of formats including visual/graphic media, text, audio, video and haptic overlays" (p. 44). Munnerley et al. (2012) specifically argue for a broad definition of Augmented Reality: "There is no need for such augmentation to be limited to the provision of visual information" (p. 41). Calo et al. (2015) concede that "there is no easy definition of 'augmented reality'" and list as features, "most of which are present in most AR systems" (p. 3) the following:

- "Sense properties about the real world.
- Process in real time.
- Output (overlay) information to the user.
- Provide contextual information.
- Recognize and track real-world objects.

- Be mobile or wearable" (pp. 3-4).

Although Calo et al. acknowledge that not all Augmented Reality systems are mobile or wearable (and that this attribute is not necessary for something to be considered AR), they express confidence that mobility will be increasingly common in the future (p. 4).

Examples of Augmented Reality systems utilizing senses other than sight include Ternier, De Vries, Börner, & Specht (2012), whose application for cultural sciences students' field trips focused on audio augmentation, arguing that "just like a user should – while driving a car – use sight as much as possible to drive, we believe that with location based learning, a learner's eyes must be primarily used to examine the environment" (§ 1 para. 2). Benko, Holz, Sinclair, & Ofek (2016) developed two systems that give haptic feedback corresponding to virtual objects (NormalTouch und TextureTouch) and although they used it for Virtual Reality (where the user moves around in an entirely virtual environment), the possibility of AR applications is brought up ("Introduction" para. 4).

Although a trend can be observed, outliers exist. *A Dictionary of Media and Communication* (Chandler & Munday, 2011) still lists Augmented Reality as "vision technologies that superimpose a computer-generated object on an image of a real-world scene", while one of the earlier attempts at classifying AR (Milgram & Kishino, 1994, p. 6) also mentions haptic and vestibular AR not just in passing but as "natural [modes] of operation."

Specht et al. (2011) are critical to over-generalization, stating that they "find these definitions too generic and in direct conceptual conflict with closely related systems such as context-aware or immersive systems, mixed reality, and personalized adaptation" (p. 117). It should however be noted that their working definition still includes senses other than vision, being "a system that enhances a person's primary senses (vision, aural, and tactile) with virtual or naturally invisible information made visible by digital means. . . . where 'view' also includes other primary human senses" (p. 117).

Another venue for discussion is the role of real environments, reflecting Augmented Reality's place on a continuum without easily definable borders. Azuma et al. (2001) bring up applications that "require removing real objects from the perceived environment, in addition to adding virtual objects. . . . Some researchers call the task of removing real objects mediated or diminished reality, but we consider it a subset of AR" (p. 34). Similarly, Wetzel, McCall, Braun, & Broll (2008) question whether the game *The Eye of Judgement* is in fact Augmented Reality, since, although physical playing cards recognized by a camera serve as input, "the

real playing field is never seen on the screen as it is completely overlaid by virtual characters and objects" (p. 177). Bringing up discussions about the seemingly disappearing borders between Augmented Reality and Virtual Reality, Jesse Schell predicts that "by 2025 we're going to have VR things and we're going to have AR things. . . . because you want them both to be good and to be good they're going to need to use different technologies and systems" (VR Intelligence, 2015, 20:32).

2.1.2 Approaches. This section is concerned with the ways in which Augmented Reality systems have been and can be constructed. It differentiates between technology and augmentation basis, loosely structured after the distinction Bower, Howe, McCredie, Robinson, & Grover (2014) make between basic hardware requirements and "other technologies" (p. 2) with which Augmented Reality experiences may be improved. Generally, the approaches discussed in section 2.1.2.1 serve as the basis for augmentation – ways in which information is transferred from the outside world to the AR system – while the technologies in section 2.1.2.2 transfer information from the device to the user.

This distinction is not perfect, as there is some overlap between the categories. For example, Azuma et al. (2001) group both displays, which are discussed in 2.1.2.2, and tracking, which is a subject of 2.1.2.1, under the category of "enabling technologies", while Papagiannakis et al. (2008) make a distinction between "technological characteristics" and "the applicability in different environments like indoor or outdoor" (p. 9), both of which would fall under Technology under the chosen classification. Despite this, for the purposes of this thesis at least, the present categorization should serve to provide some structure.

2.1.2.1 Augmentation basis. There are fundamentally two different approaches to Augmented Reality: Location-based and vision-based.

Location-based (also known as geolocated, marker-less or gravimetric (FitzGerald et al., 2013; L. Johnson et al., 2011; Munnerley et al., 2012)) AR outputs information based on the user's position. According to Munnerley et al. (2012), Points of Interest (POI) are defined and associated with virtual assets – "When a user . . . explores a space the POIs are revealed and the content can be accessed" (p. 44). This exploration can be based solely on location – usually provided through GPS – as in the application by Ternier, De Vries, et al. (2012), or take into account user orientation for increased precision (Hol, Schön, Gustafsson, & Slycke, 2006).

Vision-based (also known as artefact-based or marker-based (FitzGerald et al., 2013; Munnerley et al., 2012)) Augmented Reality functions by using computer vision techniques to identify and track patterns known as *fiducials* in the environment. You & Neumann (2001) name as examples for fiducials corner features, square shape markers, circular markers and multi-ring color markers (§ 5.1), while Munnerley et al. (2012) refer to barcodes and QR codes and go on to state that "recent developments in image recognition and mobile technology allow for any image to be used as a marker as long as it is pre-defined in the AR code" (p. 44). Papagiannakis et al. (2008) differentiate between these passive markers and active fiducials like light-emitting diodes (p. 9).

Both of these approaches have their advantages and disadvantages: Fiducials can only be used if the system has been trained to recognize them and conditions like inadequate lighting do not interfere with them (though Papagiannakis et al. (2008, p. 10) mention that using infra-red lights can vastly improve tracking quality) and thus vision-based approaches are generally best suited for prepared environments. Meanwhile location-based systems can suffer from inaccuracy or loss of tracking (for example GPS does not work indoors); marker-based tracking can be "much more stable and a simple yet often times effective solution" (Wetzel et al., 2008, p. 178).

A way to avoid the trappings and make use of the advantages of the two approaches may lie in the use of hybrid systems as described by Schall et al. (2009) or image understanding, which Furmanski, Azuma, & Daily (2002) explain "attempts to recognize structures and features with the aim of automatically describing the contents of an image" (§ 4 para. 1). The Microsoft HoloLens takes a somewhat related approach: By utilizing a depth camera and tracking head movements through various sensors, a technique called "spatial mapping" ("Spatial mapping," n.d.) can be used to construct a virtual three-dimensional model of the users' surroundings, determine their position therein, and display virtual content at the appropriate coordinates, all without the need for markers.

2.1.2.2 Technology. The work of Sutherland (1968) is frequently considered the first true Augmented Reality display (Calo et al., 2015; Feiner, MacIntyre, Höllerer, & Webster, 1997). The way his device differs from later Augmented Reality platforms highlights several areas of interest.

Firstly, there is the distinction between mobile and stationary (or desktop) AR. Though his display was restricted by the technology of the time, Sutherland stated that "eventually we would like to allow the user to walk freely about the room" (1968, p. 760), leading FitzGerald

et al. (2013) to conclude that "developers have always aimed to make AR portable" (p. 45). Calo et al. (2015) went so far as to include mobility in their list of features of AR (see section 2.1.1).

The first truly mobile Augmented Reality system, or MARS (Mulloni, Dünser, & Schmalstieg, 2010; Papagiannakis et al., 2008), was the *Touring Machine* which allowed the user to walk around relatively unconstrained, by wearing a backpack and a head-mounted display (Feiner et al., 1997).

A topic closely related to this are different types of displays. The main distinction to make in this regard is between video see-through and optical see-through. (See Azuma [1997] for a discussion on the advantages and disadvantages of these). Optical see-through refers to the projection of information while still affording the user a view of the real world. Video see-through displays on the other hand provide no direct view of the real world; instead, cameras are used to record the outside world, the video is combined with visual augmentation, and the result is displayed. A method which might be considered optical see-through, but is not as easily classified, functions by projecting information directly unto the world (outside of the device itself). A few systems have achieved this by simply using commercial projector technology (Ishii, Wisneski, Orbanes, Chun, & Paradiso, 1999; Yamabe & Nakajima, 2013), an approach which is only suitable if secrecy is not required, since it makes the information visible for anyone and additionally doesn't allow multiple users to see different images. Ishii et al. (1999) further note that their projector's brightness was insufficient, requiring them to darken the room (p. 4). Azuma et al. (2001) bring up reflective systems that do allow multiple users to see different images, while making the information visible only along the line of reflection; however, this requires objects in the world to be coated with retroreflective material, further reducing its applicability in mobile AR (p. 35). While Kruijff, Swan II, & Feiner (2010) still mention projector-camera systems, the majority of dedicated Augmented Reality systems developed today seem to utilize other kinds of display technology, as demonstrated by Calo et al. (2015)'s list of "some specific examples of AR being marketed or developed today" (p. 3) not including any such setups.

While most devices listed by Calo et al., as well as Sharma, Wild, Klemke, Helin, & Azam (2016) are head-worn (synonymous to head-mounted) displays, other types of displays such as hand-held and wrist-worn ones have also been used (Papagiannakis et al., 2008, p. 11), most notably smartphones.

2.1.3   Applications. Here, some examples are delineated of how Augmented Reality has been applied. Specifically, this part of the paper looks into educational and game applications, as well as commercial and industrial applications in general. This is only exemplary, as Augmented Reality has also been applied in other contexts such as the military and medical domain. To cover a wider field of applications or give more examples of each would however fall outside the scope of this thesis.

2.1.3.1   Commercial. A large number of examples of industrial applications have already been gathered (Azuma, 1997; Azuma et al., 2001). The section is therefore focused on more recent commercial uses of AR.

Without going into detail, Calo et al. (2015) list as domains in which AR has been applied "hands-free instruction and training, language translation, obstacle avoidance, advertising, gaming, museum tours, and much more" (p. 1). Henderson & Feiner (2009) additionally refer to maintenance and repair as "an interesting and opportunity-filled problem domain for the application of augmented reality" (p. 135), citing not only an abundance of previous work but also bringing up the existence of a number of consortiums dedicated to this field of research. The work performed by Henderson & Feiner (2009) is itself an example of successfully applying Augmented Reality to the maintenance sector: Mechanics equipped with a head-mounted AR display were able to locate tasks more quickly than those using a more traditional static screen and while task completion time did not differ significantly, the researchers found that their approach reduced overall head movement which could provide health benefits.

Nilsson, Johansson, & Jönsson (2009) conducted a study in which AR was used to support collaboration between rescue services, police and military. Presented with forest fire scenarios, the users were able to place icons on an Augmented Reality map to coordinate their strategy. Participants gave the AR system equal or higher scores than a conventional paper map and qualitative research revealed interest in applying Augmented Reality to other tasks within the three groups.

The field of Obscured Information Visualization (OIV) (Furmanski et al., 2002) has previously been used to make visible "underground infrastructures, such as water mains and electricity lines" (Schall et al., 2009, § 5 para. 1) and could potentially be applied to a wide array of maintenance tasks.

Although it had at this point not yet been applied, Olshannikova et al. (2015) propose to make use of AR in Big Data visualization, stating that it "might solve many issues from

13

narrow visual angle, navigation, scaling, etc. For example, offering a way to have a complete 360-degrees view with a helmet can solve an angle problem" (p. 18).

2.1.3.2 Education and expertise transfer. As Radu (2014) states, throughout its history "a relatively high amount of research studies have investigated the potential impact of augmented reality to benefit student learning" (p. 1533), demonstrating a high interest in this domain. In 2009, Dunleavy, Dede, & Mitchell named Augmented Reality as one of three kinds of technological interfaces "now shaping how people learn," along with "the familiar 'world- to- the- desktop' interface," and multi-user virtual environments (pp.7-8). The 2011 NMC Horizon Report (L. Johnson et al., 2011) estimated a time of 2-3 years until mainstream adoption of Augmented Reality as a tool for "teaching, learning, or creative inquiry" (p. 4). Interestingly, the same estimate was repeated in the 2016 Higher Education Edition of the Horizon Report (L. Johnson et al., 2016), showing that despite the academic interest, Augmented Reality has not managed to completely ground itself in education, though the report does express optimism that increasing ease of use will drive this development forward (p. 40).

Due to the abovementioned interest in Augmented Reality for learning, there have been not only a number of studies on the subject, but also several meta-reviews and overviews (Bower et al., 2014; FitzGerald et al., 2013; Radu, 2014). Radu (2014)'s overview of areas that have been shown to benefit from Augmented Reality applications includes learning spatial structure and function, learning language associations, long-term memory retention, improved physical task performance, improved collaboration, and increased student motivation (pp. 1534-1536).

Arguments as to why learning environments benefit from Augmented Reality have been proposed in multiple papers. As FitzGerald et al. (2013) point out, "augmenting/adding to reality has always been a part of outdoor education" (p. 49) and using Augmented Reality technology to these ends is a logical next step. Dunleavy (2014) refers to the interdependent work in physical spaces which AR allows as "the most frequently reported affordance of AR (Dunleavy, Dede, & Mitchell, 2009; Facer, Joiner, Stanton, Reid, Hull, and Kirk, 2004; Klopfer and Squire, 2008; Squire, 2010; Perry et al., 2008; Squire, Jan, Matthews, Wagler, Martin, Devane and Holden, 2007)" (p. 30).

Radu (2014) compares various media in regards to educational affordances and comes away with the following factors as influencing learning in AR (pp. 1539-1540):

- "Content is represented in novel ways";

- "Multiple representations appear at the appropriate time/space" (spatial/temporal contiguity effect);
- "The learner is physically enacting the educational concepts" ("Research shows that physical activity is linked to conceptual understanding of educational content: Shelton and Hedley, in their studies of spatial learning in AR, hypothesize that visuospatial comprehension is enhanced by physical interaction with 3D content");
- "Attention is directed to relevant content";
- "The learner is interacting with a 3D simulation" ("Digital simulations in general are effective tools because they allow students to experience phenomena that are impossible or infeasible to experience otherwise . . ., they are dynamic and interactive allowing student control over the educational content . . ., and they scaffold and assess user learning");
- "Interaction and collaboration are natural."

There is some overlap between this list and Dunleavy et al. (2009)'s enumeration of unique affordances of AR: "The greater fidelity of real world environments, the ability of team members to talk face-to-face with its bandwidth on multiple dimensions, and the capacity to promote kinesthetic learning through physical movement through richly sensory spatial contexts" (p. 8). Furthermore, Ternier, Klemke, Kalz, van Ulzen, & Specht (2012, pp. 2144-2146) cite the concept of immersive learning as an important background in the development of their mixed reality framework. Although Bower et al. (2014) criticize past efforts towards Augmented Reality learning for focusing only on "lower order thinking skills" (p. 7), they acknowledge its potential and recommend students be given design tasks in order to make better use of it. Schmitz, Specht, & Klemke (2012) mapped a number of game design patterns to cognitive and affective learning outcomes in Augmented Reality games for learning; similarly, Dunleavy (2014)'s literature review revealed three design principles for learning-oriented AR – "Enable and then challenge," "drive by gamified story," and "see the unseen" (p. 29).

2.1.3.3 Augmented Reality games. Games are an application particularly well-suited for the medium of Augmented Reality. As L. Johnson et al. (2011) state: "Augmented reality is an active, not a passive technology" (p. 17). FitzGerald et al. (2013) somewhat similarly emphasize the "dialogue between the media and the context in which it is used" (p. 44). Although commercial AR games can be said (Wetzel et al., 2008, p. 4) to go back as far as 2003's EyeToy, efforts were for a long time focused on research, until the advance of

smartphone technology, which made devices with Augmented Reality capabilities widely available and gave developers a venue (Wetzel, 2013, § 1 para. 1); however, according to Wetzel, knowledge about how to best approach the design of AR games was at the time still lacking, a sentiment Antonaci, Klemke, & Specht (2015) share: "Little is known on how to systematically apply game-design patterns to augmented reality" (p. 3). Similarly to these sources, Dunleavy (2014) attempted to extrapolate design guidelines from the AR game *Dino Dig*, which despite having educational content was primarily intended to entertain (p. 29).

One approach to the design of Augmented Reality games is concerned with translating existing games into this new medium. *PingPongPlus* (Ishii et al., 1999) uses microphones to locate the ball's points of impact on a ping pong table and utilizes a projector to augment the game according to one of several different game modes that modify the original game, for example by encouraging players to cooperate. Specht et al. (2011)'s *Locatory* is an AR adaptation of the game *Memory*, requiring players to find virtual cards spread around the environment and then match them to real landmarks. Most recently, *Pokémon GO* (Niantic, 2016), an Augmented Reality game based on the both well-known Pokémon franchise and *Ingress* (Niantic, 2013) (cited by Wetzel (2013) as a rare example of a mobile AR game with a large player base (§ 2.1)), released to great success, breaking download records (Crecente, 2016). On the other hand, Wetzel et al. (2008) criticized AR card game *The Eye of Judgement*, stating that it did "not map well to augmented reality. . . . as the game only tries to be visually more appealing than the originals but does not include genuine engaging game play" (p. 178).

2.1.4   Outlook. The following sections provide an overview of the potential of AR and what challenges it will need to overcome in order to realize said potential.

2.1.4.1   Possibilities. Several qualities of Augmented Reality may allow it to take a major role in society. As noted above, a multitude of applications have already been tested or proposed in the commercial and educational sectors. This section highlights some more general qualities.

Engagement and motivation: Several studies have pointed to Augmented Reality as being engaging and motivating, particularly for learning: "Users report feeling higher satisfaction, having more fun, and being more willing to repeat the AR experience" (Radu, 2014, p. 1536). Dunleavy et al. (2009, p. 18) found that students who had previously shown a lack of interest in their studies showed a significantly altered behavior and increased

engagement when interacting in Augmented Reality. Schmitz et al. also mapped motivational effects to Augmented Reality as a game design pattern, as demonstrated in a number of studies: "Students feel 'personally embodied' in the game. Their actions in the game are intrinsically motivated (Rosenbaum et al., 2006). Learners are attentive (Wijers et al., 2010). Students are mentally ready for learning (Schwabe and Göth, 2005)" (Schmitz et al., 2012, Table 1).

Societal: Calo et al. (2015, p. 5) point out how Augmented Reality might influence people's experiences; not only those of the AR users but also those around them, "whose features and actions may now be recorded and analyzed", as well as allowing multiple people to "perceive the same environment differently." They specifically mention the capability of Augmented Reality to replace disabled people's senses.

2.1.4.2 Challenges. Azuma et al. (2001, p. 43) see three groups of obstacles Augmented Reality has to overcome: technological limitations, user interface (UI) limitations, and social acceptance issues.

Technological: Although some limitations listed by Azuma et al. have been solved or reduced, some persist and new ones have been discovered. Kruijff et al. (2010) present an extensive catalog of issues, categorized as relating to the environment, capturing, augmentation, display, and individual user difference. Though these are stated to be based on visual processing and interpretation, the categorization also holds for location-based AR.

For instance, Dunleavy et al. (2009) mention inadequate weather conditions as restricting their studies (p. 14). FitzGerald et al. (2013, p. 51) similarly cite a need for displays that can be read in bright sunlight and devices that function in the rain, and refer to local environmental conditions as decreasing the accuracy of cheap geolocation tools while more advanced tools are costly. Another issue relates to the inaccuracy or unavailability of GPS systems indoors, and in the case of Ternier, De Vries, et al. (2012), the infrastructure of the city of Florence led to tracking issues even outdoors (§ 3 para. 6).

Biocca & Rolland (1998) investigated the effects of visual displacement, a result of the cameras used in video see-through displays not existing at the same location as the displays, calling such intersensory conflicts and the resulting adaptation "among the most critical issues in the design of immersive virtual environments" (p. 262). They report noticeably worse performance during hand-eye coordination tasks, as well as negative aftereffects. However, since modern technology allows cameras and displays to be located much closer together (in

Biocca & Rolland's study there was a displacement of 62 mm upward and 165 mm forward), this effect of visual displacement can be reasonably expected to be significantly reduced.

The task of correctly aligning real and virtual objects, known as the registration problem, is another one that has not yet been solved, despite it being "one of the most researched areas in AR" (Specht et al., 2011, p. 118). According to Azuma (1997), this task is necessary both for maintaining immersion and performing applications that require accuracy and thus "without accurate registration, augmented reality will not be accepted in many applications" (p 367).

UI: Problems related to user interfaces surfaced in many of the papers found during the literature review and can be separated into how information is displayed and how users interact with it.

Furmanski et al. (2002) investigated how to avoid depth ambiguity when visualizing obscured information and found that people tended to still rely on occlusion. Julier et al. (2000) noted that "if a graphics-based AR system is to be effective, care must be taken to ensure that its display is not cluttered with too much information" (p. 1) and developed a filter technique for this purpose. Dunleavy (2014, p. 29) similarly pointed out that "one of the most frequently reported AR design challenges is preventing student cognitive overload during the experience (Dunleavy et al., 2009; Klopfer and Squire, 2008; Perry, Klopfer, Norton, Sutch, Sanford, & Facer, 2008)."

Several studies, such as that by Specht et al. (2011, p. 125), report users developing tunnel vision and thus losing sight of their real surroundings when using AR, which included participants overlooking cars. Dunleavy (2014) expresses that in addition to the risks associated with this phenomenon, applications that intend the user to observe the environment may suffer from it, emphasizing the design metaphor of "the mobile device as a lens rather than a screen" and that "the technology needs to drive the students deeper into the authentic observation and interaction with the environment and with each other if AR is to grow beyond a novelty technology" (p. 32).

Tunnel vision is brought up by Lamantia (2009, "Missing Patterns") as one of the "gaps in the interactions current AR experiences support." The full list consists of:

- "Loner" ("Reliance on single-person, socially disconnected user experiences.");
- "Secondhand Smoke" ("Indirect experience of augmented reality.");
- "Pay No Attention to the Man Behind the Curtain" ("AR experiences that identify people by face, marker, or RFID tag could severely challenge our ability to do ordinary things.");

- "The Invisible Man!" ("AR experiences might take active measures to reinforce social mechanisms such as privacy or anonymity by actively altering the mixed-reality environment.");
- "Tunnel Vision" ("Limiting their ability to react to stimuli beyond their narrow, monocular view.");
- "AR for AR's Sake." ("Developing interaction patterns that address these everyday activities is essential.")

Generally, Radu (2014, p. 1537) notes that oftentimes participants find Augmented Reality more difficult to use than equivalent systems, although he does note that apparently this does not negatively impact motivation.

From a legal angle, Calo et al. (2015) names as "issues related to display of information" negligence, product liability, digital assault, and discrimination (p. 7).

Social acceptance: Augmented Reality systems necessarily need to gather data about the user and their surroundings. This can present a problem for "users who are not aware exactly what data is being collected or who are wary of being tracked or targeted by companies which provide personalised marketing (Hamilton, 2012)" (FitzGerald et al., 2013, p. 52). More precisely, Calo et al. (2015, p. 6) name as "issues related to the collection of information": "Reasonable expectations of privacy," "the third party doctrine," "free speech," and "intellectual property."

Other: Outside of the three major categories, one concern brought forth by some researchers (Dunleavy et al., 2009, p. 18; Wetzel et al., 2008, p. 173) is the notion that one of the factors responsible for the positive reception of AR by users is the novelty effect and that this may fade as people become more accustomed to Augmented Reality.

Finally, Radu (2014, p. 1541) stresses the investments and training necessary for Augmented Reality to be used in education – mirroring similar statements by Olshannikova et al. (2015, p. 21) about AR for Big Data Visualization – and brings up the issue of the bigger spaces Augmented Reality may require compared to traditional computer experiences.

2.2   Sensors

Sensors are a prerequisite for Augmented Reality and the choice of sensors enables different kinds of applications, such as the use of a GPS system for geolocated AR. This section will first give a brief definition of what sensors are and afterwards delve into the use of sensors in gaming and Augmented Reality respectively.

The Merriam-Webster dictionary defines a sensor as "a device that responds to a physical stimulus (as heat, light, sound, pressure, magnetism, or a particular motion) and transmits a resulting impulse (as for measurement or operating a control)." ("Sensor," 2017)

Dasarathy (1997) points to a more general definition of a "sensor as a source of information" (p. 26), which would include human sensors, but clarifies that this would make rigorous analysis much more difficult. Dasarathy also makes a distinction between three types of sensors: Active, passive, and mixed active/passive. A more in-depth classification was proposed by White (1987), based on measurands, technological aspects, detection means, conversion phenomena, sensor materials, and fields of application.

Coming from an expertise transfer background, Sharma et al. (2016) mapped high level functions to low level functions and the latter to associated sensors. The paper also provides an overview of "the state-of-the-art sensors in terms of their technical specifications, possible limitations, standards, and platforms" (p. 5). Furthermore Sharma et al. present challenges associated with linking different kinds of sensors in a system, such as incompatibility with each other or the system architecture, data synchronization and amount of data (2016, pp. 37–38).

Sensors also play an important role in the Internet of Things in which "physical items are no longer disconnected from the virtual world, but can be controlled remotely and can act as physical access points to Internet services" (Mattern & Floerkemeier, 2010, p. 242). Mattern & Floerkemeier specifically go into detail about the role of RFID (radio-frequency identification), which may be connected to sensors in order to easily communicate the sensor data to other devices.

2.2.1 Sensors in games. Sensors can be used in videogames as an alternative to more traditional inputs. "This makes the system more autonomous, and can free the user from tedious input tasks" (Lundgren & Björk, 2003, § 2.1 para. 2). As D. M. Johnson & Wiles (2003) found, simplifying input commands – as one might by using sensors – can increase concentration and engagement in the player (§ 2.1 para. 2).

This idea is not unprecedented: In the last years, gesture-based computing was introduced to many people through the Nintendo Wii – which used as its primary form of input a wireless controller that has its position tracked via an infrared sensor, allowing users to control the software by moving the controller itself – and touch-based systems like smartphones (L. Johnson et al., 2011, p. 24). The Microsoft Kinect went even further: A depth sensor and color camera allow for skeletal tracking and facial recognition, while a four-microphone array

permits voice recognition (Zhang, 2012, p. 4). Because of its capabilities and comparatively low price point, the Kinect even saw application outside of gaming, e.g. for coarse patient setup in Radiation Therapy (Bauer, Wasza, Haase, Marosi, & Hornegger, 2011).

There is however potential for games to utilize an even wider array of different sensors. Xu et al. (2009) developed a system in which a combination of electromyogram-based gesture recognition and an accelerometer could be used to solve a virtual Rubik's Cube, while Lundgren & Björk (2003, § 5.4) cite biofeedback games, which are controlled through biosensors attached to the user. Unlike the Rubik's Cube, which attempts to emulate an analog game, these biofeedback games, through their unusual interfaces, are highly different from traditional videogames. As Wetzel (2013) notes: "Different sensors have different strengths and weaknesses that completely change the way a game might work" (§ 3.3).

2.2.2 **Sensors in Augmented Reality**. Since Augmented Reality consists of augmenting the user's environment, applications depend on sensor data in order to obtain information about same environment.

While purely marker-based AR will usually rely on a camera and computer vision software, location-based AR requires tracking systems which can take a variety of forms. As examples for "locationing" technology, Wetzel (2013) mentions "GSM cells, GPS, fiducial markers, natural feature tracking, NFC/RFID as well as WiFi and Bluetooth-based proximity sensing" (§ 2.1). Although the reliability of GPS in particular has previously been criticized, including by Wetzel et al. (2008, p. 178) (referring to problems during the TimeWarp application), FitzGerald et al. (2013) observe that technological advancements in recent years have brought the most advanced locating systems to sub-centimeter accuracy (p. 47).

The amount of available sensors is one reason for the increasing use of commercial mobile devices for Augmented Reality applications, with Schmitz et al. (2012) mentioning several sensor technologies, such as GPS, RFID readers, and cameras as now being standard features (p. 1). Still, Papagiannakis et al. (2008) argue for more sensor technology in mobile Augmented Reality systems, defining as the "ultimate goal" the ability to use them "eyes-free and hands-free" while walking (p. 12). Bower et al. (2014) somewhat similarly express certainty that Augmented Reality (not explicitly referring to mobile AR) will come to include "new trigger types . . ., more intelligent input recognition . . . and increased sophistication of expression types" (p. 12).

An example of a sensor technology with major applicability for Augmented Reality that has not been fully realized is eye tracking, with few solutions currently available (Sharma et al., 2016, p. 36).

Oftentimes, different kinds of sensors are combined to improve the quality of AR experiences. As early as 1992, Robinett referred to HMDs themselves as "a multisensory display technique . . . in which the visuals depicting the surrounding three-dimensional (3-D) virtual world are generated so as to match the user's voluntary head movements" (p. 230).

Researchers have long been expanding on this fundamental hybrid system with additional sensors, frequently utilizing (extended) Kalman filters in order to combine the sensor data, though Hol et al. (2006, § 1 para. 4) cite shortcomings of the available technology as the reason, which indicates that the prevalence of combinations of sensor technology may be reduced as individual systems become more reliable. The *Touring Machine* (Feiner et al., 1997) made use of differential GPS in combination with a magnetometer and tilt sensor in order to track user location and orientation. Vision-based systems can similarly benefit from addition of sensors due to what Papagiannakis et al. (2008, p. 11) referred to as their "complimentary nature." You & Neumann (2001) combined a computer vision algorithm with an inertial sensor consisting of three orthogonal-rate gyroscopes. A hybrid system incorporating both approaches was created by Schall et al. (2009) and utilized a "Differential GPS or Real-Time Kinematic based GPS" (Abstract), an inertial measurement unit (IMU) containing gyroscopes, magnetometers and accelerometers, and a visual orientation tracker.

The Microsoft HoloLens contains an even higher number of sensors, including an IMU, four "environment understanding cameras", a depth camera, photo / video camera, a four-microphone array, and an ambient light sensor ("Order Options," n.d.), processed with a "dedicated sensor fusion processing unit" (Sharma et al., 2016, p. 19).

Finally, some Augmented Reality applications may use application-specific sensors, such as the ones related to expertise transfer listed by Sharma et al. (2016), the microphones used to detect the location of a ping pong ball by Ishii et al. (1999) or the sound sensor used by Wetzel et al. (2008) which evaluates flute notes as part of an Augmented Reality game. Specht et al. (2011) also name the affordance of Augmented Reality to visualize data the human senses cannot naturally pick up on, for instance "compass orientation, invisible light (infrared, ultraviolet, X-rays, etc.), ultrasound, or barometric pressure" (p. 118). Sensors related to this information would only make sense in specialized applications but within these could be highly valuable.

2.3 Design Patterns

In order to create a framework for interactions in Augmented Reality, it is necessary to investigate existing structures for designing systems. One such structure, which has been applied to a number of related fields, is that of the design pattern. This paper will first describe patterns in general and then how they have been used in the context of games and within the domain of Augmented Reality specifically. Design patterns are a concept first proposed for use in architecture. They describe precisely how to use design techniques in order to achieve certain positive effects, at the same time providing insight and creating a shared vocabulary in the form of a pattern language (McGee, 2007; Wetzel, 2013). More precisely, design patterns "express a relationship between particular design contexts, forces (psychological, social, or structural constraints), and desired ('positive' or good) features" (McGee, 2007, § 1 para. 3). The core goals of pattern languages, according to Wetzel (2013, § 4 para. 1) are communication, analysis, creativity and improvement.

While patterns are prescriptive, the emergence of new patterns is assumed to be a result of trial and error (McGee, 2007, § 1 para. 6), or as (Wetzel, 2013) puts it: "In order for something to qualify as a pattern, it has to have been applied in several examples already. Otherwise one might argue that it does not constitute a real pattern" (§ 7 para. 1). (Wetzel then distinguishes between *established, emergent* and *hidden* patterns.)

Since their creation, design patterns have been applied to several different fields (see Borchers, 2001, § 2) while largely retaining these core principles. Borchers (2001) presents a domain-independent, formal syntactic definition of pattern languages as directed acyclical graphs, in which each node (pattern) consists of a name, ranking, illustration, problem with forces, examples, solution, and diagram. This definition is further clarified in a set of semantics.

An example for patterns which slightly strayed from this approach are the game design patterns by Björk and Holopainen (2004). According to McGee (2007, § 1 para. 9), these are more descriptive and concerned with idea generation, discarding the "problem-solution pair templates that had previously been used" (Björk & Holopainen, 2004, p. 34). Cases like this make defining patterns somewhat difficult, especially when taking into account related but distinct concepts such as design rules "which offer advice and guidelines for specific design situations" (Zagal, Mateas, Fernández-Vara, Hochhalter, & Lichti, 2005, p. 1).

McGee (2007, § 2 para. 7) outlines the general characteristics of patterns as:

- "Operational and precise";

- "positive";

- "flexible";

- "debatable (the Pattern is clear enough to criticize)";

- "testable";

- "end-user oriented."

2.3.1   Patterns for games. Patterns for game design were first proposed by Kreimeier (2002). Calling for "a formal means to document, discuss, and plan" (para. 1) game design, as well as a shared vocabulary and rules for combining these elements, Kreimeier (para. 9) distinguishes these "content patterns" from software engineering patterns, which are concerned with how to write code, or process patterns, used in project management. Kreimeier reasons that the existence of a game design pattern language would allow for efficient communication, documentation and analysis "e.g. for purposes of comparative criticism, re-engineering, or maintenance" ("What are patterns?" para. 5).

A topic closely related to patterns is that of game mechanics. The term, developed within the game design community, is defined by Lundgren & Björk (2003) as "any part of the rule system of a game that covers one, and only one, possible kind of interaction that takes place during the game, be it general or specific" (§ 3.1 para. 1). Mechanics differ from patterns in several ways: As Lundgren & Björk state, mechanics describe only solutions while a pattern additionally contains problems and methods; different mechanics are not precisely defined – this extends to the term itself, as it has also been used in reference to programming contexts (§ 3.1 para. 2) – or structured in relation to one another (§ 9 para. 2); and finally the effects a mechanic may have on player experience are secondary or not described at all (§ 7.1 para. 1).

Addressing these concerns, Björk & Holopainen went on to formally create a collection of game design patterns (Björk & Holopainen, 2004). As mentioned above, these patterns differ from the original design patterns by not utilizing a problem-solution approach, with Björk, Lundgren, & Holopainen arguing that "not all aspects of design can or should be seen as solving problems, especially in a creative activity such as game design which requires not only engineering skills but also art and design competences" (2003, "Theoretical foundation" para. 3).

A conceptually similar approach was taken by Zagal et al. (2005). In the Game Ontology Project, they set out to create an alternative way to describe, analyze and study games, with pattern-like entries existing in a hierarchy the top level of which includes interface, rules, entity manipulation, and goals. Zagal et al. also emphasize that these are not criteria for

creating good games (p. 2). An entry is defined by title, description, strong and weak examples, parent and child elements, and potentially elements that the entry is a part of (p. 5). The ontology is based on methods from prototype theory and grounded theory.

2.3.2   Patterns for Augmented Reality and Augmented Reality games. The literature review revealed only a few pattern approaches for the general domain of Augmented Reality. In addition, the results were not design patterns but *interaction patterns*, a term that is not strictly defined in the literature. Although the examples below are presented informally by name only, it may be argued for them to fit McGee's characteristics (see section 2.3); regardless, they provide data which the framework presented in this paper was able to expand on and have thus been included.

Ternier, De Vries, et al. (2012, § 2 para. 1) refer to the "Point Of Interest" (POI) interaction pattern implemented in mobile Augmented Reality browsers. When arriving at pre-defined points (making this an interaction pattern for location-based AR), users receive information about the environment through a choice of channels. Every user is treated the same way. According to FitzGerald et al. (2013, p. 47), browsers may also direct the user towards nearby points of interest. Although one has to be present in order to perceive the information relayed at a POI, Points of Interest can be set regardless of the creator's location at any time (Munnerley et al., 2012, p. 44).

Lamantia (2009, "Painting with a Limited Palette") describes four interaction patterns, pertaining to how information is presented to the user. The *Head-Up Display* (HUD) presents information from a fixed point of view, i.e. the information is not assigned some coordinate in 3D space; normally this will align with the user's field of view. The *Tricorder* interaction pattern overlaps with the Point Of Interest pattern described above; it refers to scenarios in which information is scanned from the environment by directing the device at points of interest, adding "pieces of information to an existing real-world experience, representing them directly within the combined, augmented-reality, or mixed-reality experience" (Lamantia, 2009, "Tricorder" para. 2). *Holochess* experiences consist of presenting entirely virtual objects to the AR environment. The last interaction pattern Lamantia brings up is essentially Obscured Information Visualization (see section 2.1.3.1): *X-Ray Vision*-based experiences "[simulate] seeing beneath the surface of objects, people, or places" ("X-Ray Vision" para. 1).

There have been multiple propositions and first attempts at design patterns for Augmented Reality games, however as of yet no comprehensive list has come of it.

Schmitz et al. (2012) attempted to map design patterns for mobile games (themselves based on Björk & Holopainen's work) to cognitive and motivational effects in educational AR games. It is worth pointing out that Augmented Reality is itself one of these mobile game patterns. Although it is not included in the mobile games pattern language, Schmitz et al. also investigated the effects of the pattern "Roleplaying", stating that it "seems to be highly relevant for the design of AR learning games" (p. 3).

Antonaci et al. (2015) discuss the application and development of patterns for Augmented Reality serious games. At the end of the paper, they present a short, preliminary list of patterns "which take advantage of AR potential" (p. 7); these are however not full patterns in that they consist of only names and short descriptions. The list consists of: "Localization," "video recording and view sharing," "synchronous communication," "contextualization," and "object recognition."

One of the previous approaches listed by Antonaci et al. (2015) are the patterns for mobile mixed reality games proposed by Wetzel (2013). These patterns, Wetzel stresses, are not intended only for game design considerations, but also "other aspects of mobile mixed reality games, namely authoring, content creation, interfaces, orchestration as well as testing and logging" (2013, Abstract). The structure Wetzel (§ 5.3 paras. 2-9) settles on differs slightly from traditional design, consisting of: "Name," "categories," "problem," "solution," "examples," "description," "effects," and "connections" to other patterns.

Although they did not use the term pattern, Wetzel et al. (2008) already treaded similar ground with their "Guidelines for Designing Augmented Reality Games." These guidelines, like patterns, have easily identifiable names, with descriptions which contain examples and take the form of solutions to specific design problems. Examples (pp. 177-179) include "Experience First, Technology Second"; "Use the Real Environment"; and "Choose your tracking wisely."

2.4 Summary

Augmented Reality has been used successfully in a multitude of different domains and configurations, and definitions are growing increasingly broader. Sensor data serves as the basis for AR applications and can be used to further enhance them. Patterns as a method for organizing and defining design elements have been applied to games in general and Augmented Reality games specifically.

However, there are still some challenges for AR to overcome. These challenges inform the framework for interactions in Augmented Reality in the second part of the present thesis. The

framework is based on the pattern approach, incorporating elements from the various sources while adhering to the general characteristics laid out by McGee (2007). The patterns should also include more data than e.g. the ones listed by Antonaci et al. (2015) or Wetzel (2013). Technologically, the framework is builds on the comparison of available AR systems and sensors performed by Sharma et al. (2016).

3 Development of a Framework for Sensor-supported Augmented Reality Games

The second contribution this thesis sets out to make is a taxonomy of user interactions in Augmented Reality utilizing sensors, in the form of design patterns. This chapter begins by first describing the process used to develop the patterns, afterwards the results are presented. Then, the author describes his attempt to exemplarily implement some of the found interactions inside the Unity game engine, for use with the Microsoft HoloLens.

It is important to emphasize that the approach taken in the present paper is that of the design sciences to "create technological artifacts that augment human ability (Biocca, 1996), not ones that manipulate human abilities solely for the purpose of experimentation and observation" (Biocca & Rolland, 1998, p. 265).

Additionally, mirroring existing approaches to game design patterns described above, this is not an attempt to instruct developers on what techniques to use but simply a classification of possible interactions, akin to the game mechanic terminology. Despite such incongruities, the underlying design considerations will be referred to as patterns. In order to avoid ambiguity associated with the use of *game mechanics* to refer to techniques both in a software and a game design context, the "equivalent" (Lundgren & Björk, 2003, § 3.1 para. 2) term *mechanism* is used to refer to the (software) implementation.

3.1 Conception

First, this section describes the formal approach that was used to generate the patterns which serve as the basis for the software application (see section 3.2); afterwards, the scope of the patterns is delineated.

3.1.1 Method. The framework and the subsequent software development are based on design patterns. As these can vary in their content, the first step in constructing the framework was to compare the approaches in the papers found during the literature review (Björk & Holopainen, 2004; Borchers, 2001; Kreimeier, 2002a, 2002b; McGee, 2007; Wetzel, 2013),

summarized in Table 1. Where applicable, different terms were counted as one element. Note that this comparison is based on which elements are actually present in the examples given, regardless of other content mentioned in the papers (such as *ranking* in the Borchers paper or *context* in McGee's) – this is because examples were deemed necessary for accurate implementation of the elements.

In this first development phase of the framework, the pattern elements that were used in at least three of the five papers are present. They are:

Name: A succinct name for the pattern.

Forces/Problem: The issue or issues the pattern is intended to combat.

Feature/Solution: The core of the pattern – a description of one way to solve the problem.

Examples: Examples of how the pattern has been applied.

Effects/Consequences: The positive and negative consequences of applying the pattern. Björk & Holopainen (2004) differentiate between consequences and "using the pattern" (p. 38), the latter of which refers to other design choices required for implementing the pattern. These have been separated in the table, so as to accurately reflect the respective authors' categorization; as there is some overlap with the consequences or effects listed in the other sources, how patterns affect design choices will be brought up as *Effects* regardless. Aversely, in some instances the same term was used to mean different things. For these cases, the origin of the terms is noted in the table.

Element\Authors	McGee	Borchers	Wetzel	Björk & Holopainen	Kreimeier	Amount
Name	x	x	x	x	x	5
Forces/Problem	x	x	x		x	4
Feature/Solution	x	x	x		x	4
Illustration / Diagram		x				1
Examples		x	x	x	x	4
Context / References (Borchers) / Relations		x		x		2
Categories			x	x		2
Effects / Consequences (B&H)			x	x	x	3
(General) Description / Core Definition			x	x		2
Using the Pattern / Consequence (Kreimeier)				x	x	2
References (B&H)				x	x	2

Table 1: Elements present in pattern approaches

Because the framework is intended to also incorporate sensors and because definitions for Augmented Reality and affordances of AR systems can vary immensely, sensors which must or may be used to implement a given pattern are also present as an element in each pattern and may receive special mention in other sections. This allows game designers interested in implementing patterns to easily ascertain whether a given pattern fits their criteria.

3.1.2   Scope. Although the classification is suitable for other kinds of Augmented Reality systems, the practical part of this thesis is focused on mechanisms that can be implemented

with a Microsoft HoloLens or comparable device, as this system includes an abundance of different sensors (see section 2.2.2), can utilize techniques from both vision-based and geolocated AR due to its hybrid approach (see section 2.1.2.1), and was available to the author for testing.

As the framework utilizes a problem-based approach, not only the positive, but also the negative results of the literature study can serve as inspiration for patterns. To recapitulate, challenges to Augmented Reality can roughly be sorted into those pertaining to technology, user interface and social acceptance; due to the scope of this thesis and the framework's focus on the interactive medium of games, of these only user interfaces – visualization and interaction – will be covered. Additionally, some patterns focus on the development side of AR applications.

3.2   Patterns

Following the approach listed above resulted in the list of patterns below. The content of these is derived from the results of the literature review, a brainstorming session within the WEKIT project (Wild, 2016), and the characteristics of existing HoloLens games; however, a limited amount of time prevented significant play testing, as "analyzing the material collected from play sessions typically takes a significantly longer time than the actual sessions" (Björk & Holopainen, 2004, p. 44). Patterns referred to within the pattern description are formatted in small capitals, after Borchers (2001), so as to signify their presence, but differentiate them from application examples (unlike Björk & Holopainen (2004), which italicize both).

Name: Auto-Play

Forces/Problem: How can events in Augmented Reality be triggered without requiring or despite varying kinds of user input?

Feature/Solution: Some events may work best if started, paused and/or stopped automatically. Automatic here refers to a lack of directed efforts to create input, for example based on location or gaze. It is possible to automatize only parts of any event. Results of DIRECTED GAZE or DIRECTED MOVEMENT are not considered AUTO-PLAY as the user is clearly instructed to perform certain actions.

Examples: Applications using POINTS OF INTEREST can use varying levels of AUTO-PLAY: They either immediately make the content accessible (as with the audio recordings in Ternier, De Vries, et al. (2012)'s field trip application), or they simply notify the user of available content, allowing the user to choose if and when to retrieve it.

30

Effects/Consequences: Content presented automatically can allow the user to avoid tunnel vision and make using the application more pleasant as less effort is required. Automatic warnings can prevent injury or incorrect use. If too much information is communicated too suddenly, AUTO-PLAY could also confuse or disorient the user or cause screen clutter. If there is no apparent way to remove unwanted content, the user may become frustrated.

Sensors: What sensors are necessary for this is entirely dependent on the application. Automatic content may for example be based on position, gaze/orientation, audio input, or fiducials.

Name: Directed Gaze

Forces/Problem: How do you direct a user's attention to something when they have full control over their view?

Feature/Solution: Use an icon to indicate something the user should direct their attention towards. Affix the icon to the screen, pointing towards the object of interest if it is not currently visible; possibly remove the icon while the user looks at the point.

Examples: Asobo Studio's *Fragments* (2016a) and *Young Conker* (2016b) use DIRECTED GAZE at some points to direct the player towards important information. This may be combined with GAZE POINT OF INTEREST.

Effects/Consequences: DIRECTED GAZE icons can make for a more structured AR experience and avoid user confusion. However, they may obstruct other, possibly important elements and cause screen clutter. If multiple focus points exist at a time, INFORMATION FILTERING may prove necessary to avoid this. To communicate to the user where the system currently assumes their gaze is directed, use a GAZE CURSOR.

Sensors: The system always needs to be aware of the position of the focus point relative to the user's location and head rotation. How this works is dependent on the AR device, but generally, IMUs will be most useful for this.

Name: Directed Movement

Forces/Problem: Some applications may require the user to move to certain locations. How do you communicate these?

Feature/Solution: Display an icon at the target location (either on a map or in the user's field of view, based on orientation); affix the icon to the screen, pointing towards the object of

interest if it is not currently visible; possibly remove the icon while the user is located at the point.

Examples: On a macro-scale, a POINT OF INTEREST can serve as a form of DIRECTED MOVEMENT if permanently displayed on a map and/or in direction.

Effects/Consequences: DIRECTED MOVEMENT icons can make for a more structured AR experience and avoid user confusion. However, they may obstruct other, possibly important elements and cause screen clutter. If multiple focus points exist at a time, INFORMATION FILTERING may prove necessary to avoid this.

Sensors: The system always needs to be aware of the position of the focus point relative to the user's position and possibly orientation. How this works is dependent on the AR device; purely location-based systems can utilize e.g. GPS sensors. IMUs may allow for three-dimensional instructions using the user's head orientation.

Name: Environment-Adaption

Forces/Problem: How do you design a game that can be run anywhere while still taking into account the characteristics of that specific environment?

Feature/Solution: Make the game automatically adapt to the characteristics of the environment.

Examples: The levels and character interactions in *Young Conker* (Asobo Studio, 2016b) are based on local characteristics, e.g. the player character teeters when near ledges. *Fragments* (Asobo Studio, 2016a) automatically finds surfaces with specific characteristics – for instance height and surface size – for characters to sit on.

Effects/Consequences: The game will be able to run anywhere (unrelated issues notwithstanding) while making use of the affordances of Augmented Reality. However, they cannot be planned as stringently and different users may have entirely different experiences.

Sensors: Required sensors depend on the degree of interaction and specifics of the application. For general purposes, depth sensors may be sufficient.

Name: Environment-Independence

Forces/Problem: How can you develop AR games for unknown environments?

Feature/Solution: Make the game not interact with the environment.

Examples: Universal Windows Platform games not optimized for the HoloLens are presented in windows which can be placed on surfaces while the games themselves do not account for

the environment. Location-based games like *Pokémon GO* (Niantic, 2016) may take into account map data but will ignore current local conditions.

Effects/Consequences: ENVIRONMENT-INDEPENDENT games are simpler in their construction and will function more reliably and predictably. However, their classification as Augmented Reality may be questioned and users may not get as much enjoyment out of them as more interactive applications.

Sensors: Aside from the sensors needed for the system itself, ENVIRONMENT-INDEPENDENT games are intended to function without extra sensors.

Name: Environment Requirements

Forces/Problem: How can you design a game which interacts with environments without changing the game itself?

Feature/Solution: Make the game require certain environmental features.

Examples: Games based on fiducial markers require a prepared environment. Some AR applications such as the *Touring Machine* (Feiner et al., 1997) are designed for use in one specific location. *Locatory* (Specht et al., 2011) expects the user to match virtual images to real locations which need to be defined before a play session.

Effects/Consequences: Having ENVIRONMENT REQUIREMENTS ensures that a game works as intended (other issues notwithstanding) while still making use of the affordances of Augmented Reality. However, having certain requirements means that some users will be unable or unwilling (refusing to make changes to their environment) to play the game.

Sensors: Required sensors are highly application-dependent but may include a camera with computer vision algorithms for fiducials or a depth sensor for more involved spatial understanding.

Name: Gaze Cursor

Forces/Problem: In an environment with multiple interactive objects, how do you select which ones to apply actions to?

Feature/Solution: Base actions on the user's gaze or orientation and communicate this process graphically as with a computer's cursor. The GAZE CURSOR can be used either for only selecting objects or for completing actions, for example based on duration of gaze.

Examples: Various HoloLens applications utilize GAZE CURSORS, such as *RoboRaid* (Microsoft, 2016) for targeting enemies and *Young Conker* (Asobo Studio, 2016b) for

controlling the player character. In a broader sense, the entirety of the scene taken in by the camera in a marker-based AR system can be considered to be under the GAZE CURSOR.

Effects/Consequences: Using a GAZE CURSOR should make interactions more clear to the user if the cursor is accurate and consistent. Inaccurate, inconsistent, or lagging cursors may however make interaction frustrating and unreliable. A graphical representation of the user's gaze will take up screen space – one should ensure that the object of the user's interest is not obscured by the cursor. There might also be a danger of tunnel vision.

Sensors: The system must be aware of the user's gaze, which can be achieved by tracking their head movements. Eye tracking can provide a higher degree of accuracy if available.

Name: Gaze Point of Interest

Forces/Problem: How can events in Augmented Reality be triggered?

Feature/Solution: Have the game system perform actions when the player looks at specific objects (real or virtual), either immediately or once the gaze has been focused on the object for a certain amount of time. Different events may execute when something leaves the player's field of view.

Examples: This is the basis for all marker-based AR – once a marker comes into view, actions pertaining to it may execute. *Fragments* (Asobo Studio, 2016a) at certain points uses DIRECTED GAZE to draw the player's attention, then progresses after they have looked at the focus point for some amount of time.

Effects/Consequences: GAZE POINT OF INTEREST may ensure that the user's attention is focused on important information or allow for context-sensitive information to be delivered through AUTO-PLAY for a more immersive experience. If combined with a GAZE CURSOR, it can provide feedback on selected objects. Executed poorly, using GAZE POINT OF INTEREST can worsen the user experience, transforming the very thing the user is attempting to look at. In some cases, such as information bound to larger areas, a POINT OF INTEREST may be more appropriate. If this feature is not communicated clearly, the user may be confused by unintended events.

Sensors: Combined with location data and a known environment, IMUs can be used to determine what the user's gaze is focused on. Alternatively, a camera with computer vision algorithms may be used.

Name: Gesture-based Interaction

Forces/Problem: How can users interact intuitively with AR environments?

Feature/Solution: Allow the manipulation of objects through gestures.

Examples: Gestures are one of the three forms of interaction for HoloLens applications. RoboRaid (Microsoft, 2016) for example has the user shoot targets by performing a hand motion. Games have previously used gestures to control games for the Microsoft Kinect. Touch displays are controlled through gestures on the screen.

Effects/Consequences: Without additional input devices, AR systems may be more immersive and intuitive to use. However, users may accidentally make inputs. If inputs are not intuitive or require too much effort, the users may become frustrated.

Sensors: Gestures can be used as input with specialized devices such as the Leap Motion, Myo armband or Microsoft Kinect. Simple gesture recognition could also be implemented with only a camera and computer vision algorithms.

Name: Haptic Feedback

Forces/Problem: User may miss visual or audio feedback; user does not receive appropriate feedback when "touching" augmented objects.

Feature/Solution: Give feedback via the haptic sense.

Examples: Vibrotactile feedback, a form of HAPTIC FEEDBACK, is a standard feature of game controllers. The Myo Armband can give such feedback while keeping the user's hands free. The NormalTouch and TextureTouch devices (Benko et al., 2016) are able to give somewhat accurate haptic representations of virtual objects.

Effects/Consequences: Users may be more responsive to HAPTIC FEEDBACK, especially if their attention is not on the augmentation. The AR device has to implement haptic technology, or other devices have to be added – if the user has to hold the feedback device in one or more hands, their freedom of movement will be limited. (Inappropriate) HAPTIC FEEDBACK may break immersion.

Sensors: If accurate feedback corresponding to body movements is to be given, hand or full-body tracking must be used (e.g. with Leap Motion or Kinect).

Name: Information Filtering

Forces/Problem: Too much information available at a time will clutter the screen and make the application more difficult to use. Too little information will make the application less useful.

Feature/Solution: Filter information e.g. by distance and angle of gaze.

Examples: Julier et al. (2000) utilized INFORMATION FILTERING in their sniper avoidance system. In the detective game *Fragments* (Asobo Studio, 2016a) new evidence may only materialize upon approaching it.

Effects/Consequences: INFORMATION FILTERING makes systems easier to use. Designers need to ensure that the filter parameters reflect the intention of the application to avoid presenting too little or too much information.

Sensors: Sensors depend on the exact filter approach, e.g. if distance and viewing angle are to be used, the system needs access to this data, for instance through IMUs and geolocation systems.

Name: Obscured Information Visualization

Forces/Problem: Some applications may want the users to keep track of content that is hidden behind other objects, real or virtual, at a given time.

Feature/Solution: Augment the object by visualizing it even, or specifically, if it is obscured (various approaches).

Examples: Furmanski et al. (2002) explored multiple design approaches to OBSCURED INFORMATION VISUALIZATION and compared their effectiveness, though they note a number of factors which might have influenced the results. *Young Conker* (Asobo Studio, 2016b) has the main character visible even when obscured by real objects.

Effects/Consequences: OBSCURED INFORMATION VISUALIZATION can afford the user a better understanding of their (augmented) environment. However, inappropriate approaches may cause depth perception issues.

Sensors: The system needs to be aware of the positions and rotations of both real objects and the augmented content, therefore a completely passive marker-based solution will not work; active RFID chips could function but the most reliable approaches visualize static or completely virtual objects in a known environment through head tracking, e.g. with IMUs.

Name: Point of Interest

Forces/Problem: How can information be provided to users in a location-based system? How can information be bound to locations that are not reasonably accessible to developers?

Feature/Solution: Bind information to location data, automatically making it available to the user upon getting within a predefined range and allowing you to direct users to such points.

Examples: Several Augmented Reality browsers have implemented POINT OF INTEREST approaches. Ternier, De Vries, et al. (2012) utilized it to guide students on a field trip. The game *Alien Contact!* (Dunleavy et al., 2009) is based on POINTS OF INTEREST represented by real objects.

Effects/Consequences: POINTS OF INTEREST either cannot overlap or the system requires a method to handle such overlap. Constantly gathering information about user location and comparing it to POINTS OF INTEREST may consume a lot of energy, which could negatively affect the user, especially in mobile AR systems. If the user is guided towards POINTS OF INTEREST, care must be taken to avoid screen clutter and information overload. A degree of precision is lost if only location data is used – it may be preferable to combine or replace a POINT OF INTEREST with a GAZE POINT OF INTEREST.

Sensors: Requires location technology such as GPS sensors or IMUs in vision-based systems with a local coordinate system.

Name: Shared Pointer

Forces/Problem: How can multiple people in an Augmented Reality environment communicate efficiently?

Feature/Solution: Use (gaze) cursors which are also visible to the other players or allow users to leave markers at set points.

Examples: Nilsson et al. (2009) used SHARED POINTERS in the form of settable icons in all versions of their cross-organizational collaboration application and a form of cursor in the first version.

Effects/Consequences: SHARED POINTERS can allow users to communicate more clearly. This approach requires either a GAZE CURSOR or some other kind of directed user input. For consequences of users setting markers, see DIRECTED GAZE and DIRECTED MOVEMENT (though depending on your application it may not be necessary for the markers to be pointed towards when off-screen).

Sensors: If a GAZE CURSOR is used, the sensors related to it are needed. If only virtual objects can be selected, special sensors may not be necessary. If real objects can also be targeted, the relative positions and orientations of the users must be taken into account, derived from e.g. IMU data.

Name: Voice Commands

Forces/Problem: How do you allow user input while keeping the user's hands free?

Feature/Solution: Have the user perform actions by speaking appropriate phrases.

Examples: VOICE COMMANDS are a standard feature of HoloLens applications and can be seen in games such as *RoboRaid* (Microsoft, 2016) where a voice command is used to activate a special ability. *Fragments* (Asobo Studio, 2016a) gives you a choice between GESTURE-BASED INTERACTION and VOICE COMMANDS, e.g. for examining objects.

Effects/Consequences: If implemented well, VOICE COMMANDS can greatly enhance user experience. However, if phrase recognition does not work well or the phrases are too complicated, the user may become frustrated. If the application is to be used in shared spaces, loudly talking and recording audio without consent may face social acceptance issues; the system could also pick up other people's voices and act accordingly, against the user's wishes.

Sensors: Necessitates one or more microphones.

3.3 Implementation

The software implementation was first intended to be based in its structure on the ARLearn system described by Ternier, Klemke, et al. (2012, §§ 4-5), with a few differences based on the dissimilar usage scenarios. However, early during development it became clear that, due to limitations in time, this first stage of development should only be concerned with implementing mechanisms that could function independently, with the possibility of unifying them in a shared system like ARLearn later on.

As mentioned previously, the patterns have been developed for the HoloLens, inside the Unity game engine (version 5.5). Additionally, a multitude of resources for HoloLens development in Unity exists: The *Holographic Academy* (https://developer.microsoft.com/en-us/windows/holographic/academy) is a collection of tutorials and code examples on the basics of HoloLens development. The *HoloToolkit*, parts of which are used in the *Holographic Academy,* "is a collection of scripts and components intended to accelerate the development of holographic applications targeting Windows Holographic" ("HoloToolkit," n.d.). As both

of these resources are about fundamental elements for designing HoloLens applications, there exists some overlap between them and the patterns described above. VOICE COMMANDS, for example, are entirely covered. In cases such as this one, a decision was made against developing comparable approaches from the ground up, as this seemed redundant; instead, an attempt was made to build upon the existing code where possible without sacrificing the generic nature of the patterns.

Although the author did not have access to a HoloLens device at all times, the version of the engine that was used allows for *Holographic Simulation*, in which much of the functionality of the HoloLens can be emulated on computers running the Windows 10 operating system, including full body and head movement, gesture input (all through a game controller), and voice commands, all inside virtual rooms. All in all, the emulator allows for at least approximation of the majority of "fundamental building blocks" ("Development overview," n.d.) of HoloLens development – world coordinates, gaze input, gesture input, voice input, spatial sound, and spatial mapping – all of which were utilized for the framework.

One example of a feature that is available in the simulation only in a limited capacity is "spatial understanding," a process related to spatial mapping in which spatial data is interpreted, e.g. for identifying walls, floors and ceilings. The holographic academy utilizes a much simplified version of this which is based only on surface orientation. The more sophisticated implementation that is part of HoloToolkit does not return usable data when started inside the Unity editor, as the code specifically checks the software environment it is running in and operates accordingly (even when modified to function inside the engine, an environmental scanning process is started but does not progress).

The framework's implementation, written in C#, consists of 13 core scripts and a few helper classes (which are applied in the example scenes or can be used for testing but are not essential or are heavily based on existing scripts). Figure 2 shows the relations between the core scripts.
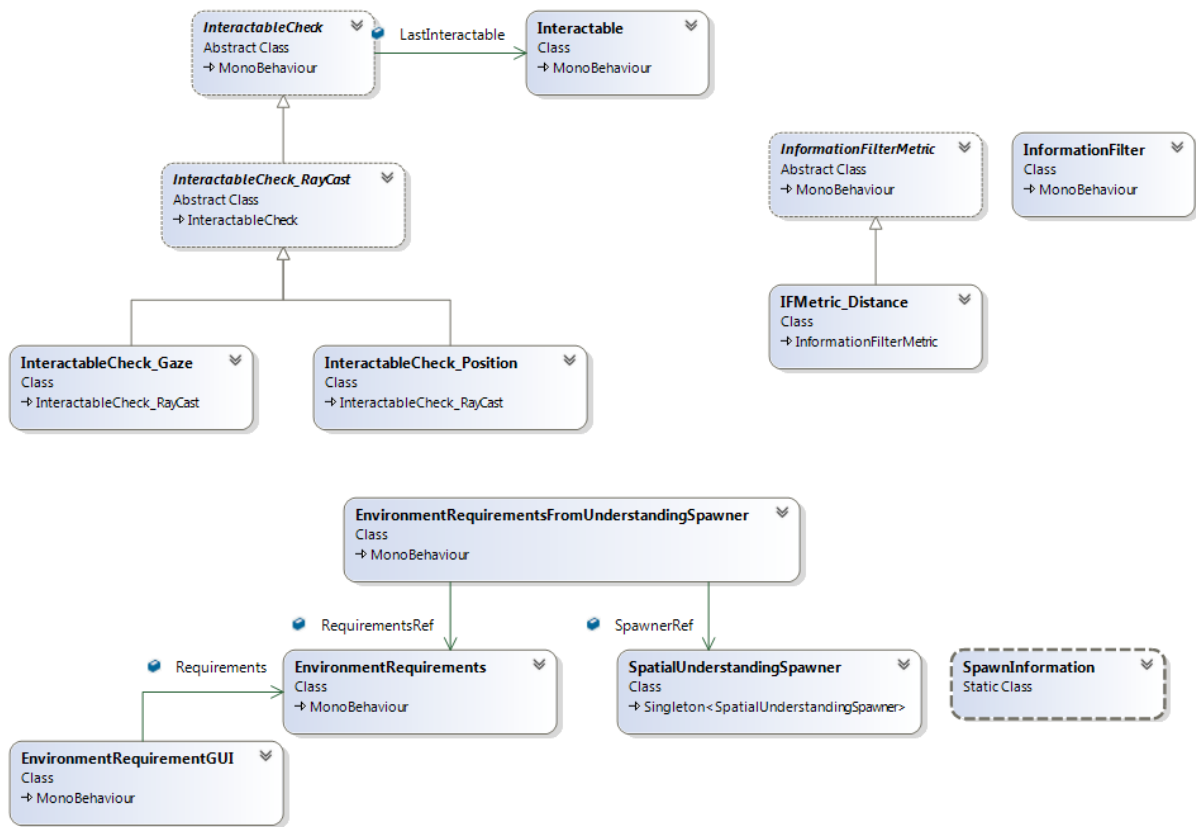
Figure 2: Game mechanism framework class diagram

Interactable, *InteractableCheck_Gaze*, and *InteractableCheck_Position* together form the basis for the mechanisms POINT OF INTEREST and GAZE POINT OF INTEREST. The scripts inheriting from *InteractableCheck* provide different ways of detecting *Interactable* objects and call specific methods therein (Enter(), Stay(), and Exit()). What type of interaction an object supports is based on the layer it is placed on inside of Unity.

The *EnvironmentRequirements* class implements the pattern of the same name. Requirements consist of an environmental feature, an amount, and whether the amount represents an upper or lower limit. This data is compared to that gathered by the HoloLens. *EnvironmentRequirementGUI* represents one way of visualizing the available information.

The spatial understanding features of the device are further utilized in *SpatialUnderstandingSpawner*, an implementation of ENVIRONMENT-ADAPTION which uses predefined sets of rules and constraints from *SpawnInformation* to find suitable spots for instantiating objects, e.g. on a wall or on a floor, far from the player.

EnvironmentRequirementsFromUnderstandingSpawner provides a bridge between the two previous mechanisms by generating simple requirements from the parameters of a *SpatialUnderstandingSpawner*.

Finally, *InformationFilter* is, as the name suggests, an implementation of INFORMATION FILTERING, executing tasks according to rules based on the data from *InformationFilterMetric*-derived classes, such as *IFMetric_Distance*, which takes into account the distance between the object it is placed on and e.g. the player.

3.4   Results

At this point, the software adaptation contains several patterns as game mechanisms, demonstrated in four example setups (scenes) in Unity, all usable on the HoloLens and, where possible, inside the engine.

As stated before, some of the patterns had already been sufficiently implemented, e.g. as part of the HoloToolkit library. A few of them were included (in some cases slightly modified) in the example scenes in order to demonstrate how they can interact with the other mechanisms. The full list consists of DIRECTED GAZE and DIRECTED MOVEMENT (as one script), GAZE CURSOR, GESTURE-BASED INTERACTION, and VOICE COMMANDS.

POINT OF INTEREST and GAZE POINT OF INTEREST are included in a simple test scene, which can be run without a HoloLens.

ENVIRONMENT-ADAPTATION is demonstrated in a Unity scene called "BoxSpawner," in which, once the room has been scanned, a virtual box is created at a random spot on the floor of the room (by default, though this can easily be changed within Unity); once this GAZE POINT OF INTEREST is looked at for a half second, the object is deactivated and a new one generated.

Relatedly, ENVIRONMENT REQUIREMENTS are available and showcased in a scene in which requirements to the playspace, based on spatial understanding, are listed before the room is scanned; during the scanning process the data captured by the HoloLens is constantly compared with the requirements, allowing the user to move on only once all conditions are met (see Figure 3: Environment Requirements). The scene "RequirementSpawner" precedes these actions with automatically generating a set of ENVIRONMENT REQUIREMENTS based on one usage scenario.

The INFORMATION FILTERING pattern at this point exists in a scene and group of classes which perform actions according to different levels of proximity to the user, but are generic enough to easily expand on. Being based around location data, the INFORMATION FILTERING class can also be considered an alternative approach to a POINT OF INTEREST mechanism.

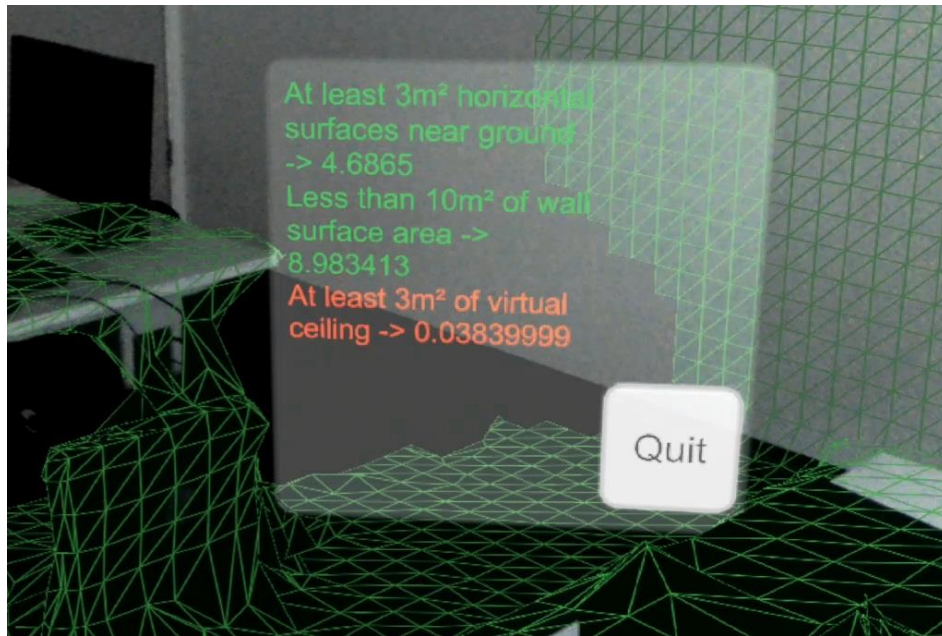All of these mechanisms are intertwined in the scene "AllMechanisms."

Figure 3: Environment Requirements example scene running on the HoloLens

4   Conclusion

The author has presented an overview of Augmented Reality definitions, approaches and applications, as well as sensors and design patterns. Based on this research, he developed a number of design patterns and exemplarily adapted a sample of them as mechanisms in the Unity game engine.

The work performed in this thesis could be expanded in several ways. The patterns listed only cover a fraction of AR interactions, as the scope was limited to user interaction and usability with the Microsoft HoloLens, and even under these limitations is likely not complete. In addition, not all of the patterns are covered in the software application. Although the software runs on HoloLens, it has not been thoroughly optimized. In any case, the results can be seen as a proof of concept and may serve as a basis for future work.

Despite coming from a game design background, the patterns described and the software developed could be used in other Augmented Reality contexts such as the commercial applications mentioned in section 2.1.3.1 or more general expertise transfer applications like the WEKIT project.

Augmented Reality as a field is only starting to be integrated into the mainstream and new technologies and approaches have the potential to fundamentally change it as the HoloLens promises.

5   References

Antonaci, A., Klemke, R., & Specht, M. (2015). Towards Design Patterns for Augmented Reality Serious Games. In *The Mobile Learning Voyage - From Small Ripples to Massive Open Waters* (pp. 273–282). https://doi.org/10.1007/978-3-319-25684-9_20

Asobo Studio. (2016a). Fragments. Redmond, WA: Microsoft.

Asobo Studio. (2016b). Young Conker. Redmond, WA: Microsoft.

Azuma, R. T. (1997). A Survey of Augmented Reality. *Presence: Teleoperators and Virtual Environments*, *6*(4), 355–385. Retrieved from http://www.dca.fee.unicamp.br/~leopini/DISCIPLINAS/IA369T-22014/Seminarios-entregues/Grupos-Visualização/Visualizacao-Gr-LuisPattam-paperdeapoio-1.pdf

Azuma, R. T., Baillot, Y., Behringer, R., Feiner, S., Julier, S., & MacIntyre, B. (2001). Recent advances in augmented reality. *IEEE Computer Graphics and Applications*, *21*(6), 34–47. https://doi.org/10.4061/2011/908468

Bauer, S., Wasza, J., Haase, S., Marosi, N., & Hornegger, J. (2011). Multi-modal Surface Registration for Markerless Initial Patient Setup in Radiation Therapy using Microsoft's Kinect Sensor. In *Proc. IEEE Workshop on Consumer Depth Cameras for Computer Vision (CDC4CV)* (pp. 1175–1181). IEEE Press. Retrieved from http://www5.informatik.uni-erlangen.de/Forschung/Publikationen/2011/Bauer11-MSR.pdf

Benko, H., Holz, C., Sinclair, M., & Ofek, E. (2016). NormalTouch and TextureTouch : High-fidelity 3D Haptic Shape Rendering on Handheld Virtual Reality Controllers. In *Proceedings of the 29th Annual Symposium on User Interface Software and Technology* (pp. 717–728). ACM. https://doi.org/10.1145/2984511.2984526

Biocca, F. A., & Rolland, J. P. (1998). Virtual Eyes Can Rearrange Your Body: Adaptation to Visual Displacement in See-Through, Head-Mounted Displays. *Presence: Teleoperators and Virtual Environments*, *7*(3), 262–277. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.541.8417&rep=rep1&type=pdf

Björk, S., & Holopainen, J. (2004). *Patterns in Game Design* (1st ed.). Hingham, MA: Charles River Media.

Björk, S., Lundgren, S., & Holopainen, J. (2003). Game Design Patterns. In *Level Up: Digital Games Research Conference 2003*. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.10.4097&rep=rep1&type=pdf

Borchers, J. O. (2001). A Pattern Approach to Interaction Design. *AI & Society*, *15*(4), 359–376. Retrieved from https://guzdial.cc.gatech.edu/hci-seminar/uploads/1/BorchersInteractionPatterns.pdf

Bower, M., Howe, C., McCredie, N., Robinson, A., & Grover, D. (2014). Augmented Reality in education – cases, places and potentials. *Educational Media International*, *51*(1), 1–15. https://doi.org/10.1080/09523987.2014.889400

Calo, R., Denning, T., Friedman, B., Kohno, T., Magassa, L., McReynolds, E., … Woo, J. (2015). Augmented Reality: A Technology and Policy Primer. Retrieved from http://techpolicylab.org/wp-content/uploads/2016/02/Augmented_Reality_Primer-TechPolicyLab.pdf

Chandler, D., & Munday, R. (2011). augmented reality. In *A Dictionary of Media and Communication*. Oxford University Press. Retrieved from http://www.oxfordreference.com/view/10.1093/acref/9780199568758.001.0001/acref-9780199568758-e-0171

Crecente, B. (2016). Pokémon Go breaks iTunes record, Apple confirms. Retrieved February 8, 2017, from http://www.polygon.com/2016/7/22/12258490/pokemon-go-itunes-record-apple-confirms

Dasarathy, B. V. (1997). Sensor fusion potential exploitation-innovative architectures and illustrative applications. *Proceedings of the IEEE*, *85*(1), 24–38. https://doi.org/10.1109/5.554206

Development overview. (n.d.). Retrieved February 8, 2017, from https://developer.microsoft.com/en-us/windows/holographic/development_overview

Dunleavy, M. (2014). Design Principles for Augmented Reality Learning. *TechTrends*, *58*(1), 28–34. https://doi.org/10.1007/s11528-013-0717-2

Dunleavy, M., Dede, C., & Mitchell, R. (2009). Affordances and limitations of immersive participatory augmented reality simulations for teaching and learning. *Journal of Science Education and Technology*, *18*(1), 7–22. https://doi.org/10.1007/s10956-008-9119-1

Feiner, S., MacIntyre, B., Höllerer, T., & Webster, A. (1997). A Touring Machine: Prototyping 3D Mobile Augmented Reality Systems for Exploring the Urban Environment. *Personal Technologies*, *1*(4), 208–217. Retrieved from https://www.researchgate.net/profile/Blair_Macintyre/publication/221240775_A_Touring_Machine_Prototyping_3D_Mobile_Augmented_Reality_Systems_for_Exploring_the_Urban_Environment/links/0f31753c5290d35949000000.pdf

FitzGerald, E., Ferguson, R., Adams, A., Gaved, M., Mor, Y., & Thomas, R. (2013). Augmented reality and mobile learning: the state of the art. *International Journal of Mobile and Blended Learning*, *5*(4), 43–58. Retrieved from http://oro.open.ac.uk/38386/8/__userdata_documents4_ctb44_Desktop_FitzGerald paper-IJMBL 5%284%29.pdf

Furmanski, C., Azuma, R. T., & Daily, M. (2002). Augmented-reality visualizations guided by cognition: Perceptual heuristics for combining visible and obscured information. In *Proceedings of the International Symposium on Mixed and Augmented Reality (ISMAR'02)*. IEEE. https://doi.org/10.1109/ISMAR.2002.1115091

Henderson, S. J., & Feiner, S. (2009). Evaluating the benefits of augmented reality for task localization in maintenance of an armored personnel carrier turret. In *IEEE International Symposium on Mixed and Augmented Reality 2009* (pp. 135–144). IEEE. https://doi.org/10.1109/ISMAR.2009.5336486

Hol, J. D., Schön, T. B., Gustafsson, F., & Slycke, P. J. (2006). Sensor Fusion for Augmented Reality. In *2006 9th International Conference on Information Fusion* (pp. 1–6). IEEE. https://doi.org/10.1109/ICIF.2006.301604

HoloToolkit. (n.d.). Retrieved February 8, 2017, from https://github.com/Microsoft/HoloToolkit

Ishii, H., Wisneski, C., Orbanes, J., Chun, B., & Paradiso, J. (1999). PingPongPlus: design of an athletic-tangible interface for computer-supported cooperative play. In *Proceedings of the SIGCHI conference on Human factors in computing systems*. ACM. https://doi.org/http://doi.acm.org/10.1145/302979.303115

Johnson, D. M., & Wiles, J. (2003). Effective Affective User Interface Design in Games. *Ergonomics*, *46*(13/14), 1332–1345. Retrieved from http://eprints.qut.edu.au/6693/1/6693.pdf

Johnson, L., Adams Becker, S., Cummins, M., Estrada, V., Freeman, A., & Hall, C. (2016). *NMC Horizon Report: 2016 Higher Education Edition.* Austin, Texas: The New Media Consortium. Retrieved from http://cdn.nmc.org/media/2016-nmc-horizon-report-he-EN.pdf

Johnson, L., Smith, R., Willis, H., Levine, A., & Haywood, K. (2011). *The 2011 Horizon Report*. Austin, Texas: The New Media Consortium. Retrieved from http://www.nmc.org/pdf/2011-Horizon-Report.pdf

Julier, S., Lanzagorta, M., Baillot, Y., Rosenblum, L., Feiner, S., Höllerer, T., & Sestito, S.

(2000). Information filtering for mobile augmented reality. In *Proceedings - IEEE and ACM International Symposium on Augmented Reality, ISAR 2000* (pp. 3–11). IEEE. https://doi.org/10.1109/ISAR.2000.880917

Kreimeier, B. (2002a). The Case For Game Design Patterns. Retrieved February 8, 2017, from http://www.gamasutra.com/view/feature/4261/the_case_for

Kreimeier, B. (2002b). The Case For Game Design Patterns. Retrieved February 8, 2017, from http://www.gamasutra.com/view/feature/132649/the_case_for_game_design_patterns.php?page=2

Kruijff, E., Swan II, J. E., & Feiner, S. (2010). Perceptual Issues in Augmented Reality Revisited. Retrieved from http://www.icg.tu-graz.ac.at/Members/kruijff/perceptual_issues_AR.pdf

Lamantia, J. (2009). Inside Out: Interaction Design for Augmented Reality. Retrieved February 8, 2017, from http://www.uxmatters.com/mt/archives/2009/08/inside-out-interaction-design-for-augmented-reality.php

Lundgren, S., & Björk, S. (2003). Game Mechanics: Describing Computer-Augmented Games in Terms of Interaction. In *Proceedings of TIDSE '03*. Retrieved from http://www.cse.chalmers.se/research/group/idc/publication/pdf/lundgren_bjork_game_mechanics.pdf

Mattern, F., & Floerkemeier, C. (2010). From the Internet of Computers to the Internet of Things. In K. Sachs, I. Petrov, & P. Guerrero (Eds.), *From Active Data Management to Event-Based Systems and More (Lecture Notes in Computer Science, 6462)* (pp. 242–259). Springer Berlin Heidelberg. Retrieved from http://ruangbacafmipa.staff.ub.ac.id/files/2012/02/ebooksclub.org__From_Active_Data_Management_to_Event_Based_Systems_and_More.pdf#page=258

McGee, K. (2007). Patterns and Computer Game Design Innovation. In *Proceedings of the 4th Australasian conference on Interactive entertainment*. RMIT University. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.90.29&rep=rep1&type=pdf

Microsoft. (2016). RoboRaid. Redmond, WA: Microsoft.

Milgram, P., & Kishino, F. (1994). A Taxonomy of Mixed Reality Visual Displays. *IEICE Transactions on Information and Systems*, *77*(12), 1321–1329. Retrieved from https://cs.gmu.edu/~zduric/cs499/Readings/r76JBo-Milgram_IEICE_1994.pdf

Mulloni, A., Dünser, A., & Schmalstieg, D. (2010). Zooming Interfaces for Augmented Reality Browsers. In *Proceedings of the 12th international conference on Human computer interaction with mobile devices and services* (pp. 161–170). New York: ACM. https://doi.org/10.1145/1851600.1851629

Munnerley, D., Bacon, M., Wilson, A., Steele, J., Hedberg, J., & Fitzgerald, R. (2012). Confronting an augmented reality. *Research in Lerning Technology*, *20*, 39–48. https://doi.org/10.3402/rlt.v20i0.19189

Niantic. (2013). Ingress. San Francisco, CA: Niantic.

Niantic. (2016). Pokémon GO. San Francisco, CA: Niantic.

Nilsson, S., Johansson, B., & Jönsson, A. (2009). Using AR to support cross-organisational collaboration in dynamic tasks. In *In Proceedings of the 8th IEEE International Symposium on Mixed and Augmented Reality, ISMAR* (pp. 3–12). Washington, DC: IEEE Computer Society. https://doi.org/10.1109/ISMAR.2009.5336522

Olshannikova, E., Ometov, A., Koucheryavy, Y., & Olsson, T. (2015). Visualizing Big Data with augmented and virtual reality: challenges and research agenda. *Journal of Big Data*, *2*(1). https://doi.org/10.1186/s40537-015-0031-2

Order Options. (n.d.). Retrieved February 8, 2017, from https://www.microsoft.com/microsoft-hololens/en-US/buy

Papagiannakis, G., Singh, G., & Magnenat-Thalmann, N. (2008). A survey of mobile and wireless technologies for augmented reality systems. Retrieved from http://calhoun.nps.edu/bitstream/handle/10945/41253/Singh_d912f5075af50e0812_2008 .pdf?sequence=1

Radu, I. (2014). Augmented reality in education: a meta-review and cross-media analysis. *Personal and Ubiquitous Computing*, *18*(6), 1533–1543. https://doi.org/10.1007/s00779-013-0747-y

Robinett, W. (1992). Synthetic experience: a proposed taxonomy. *Presence: Teleoperators and Virtual Environments*, *1*(2), 229–247.

Schall, G., Wagner, D., Reitmayr, G., Taichmann, E., Wieser, M., Schmalstieg, D., & Hofmann-Wellenhof, B. (2009). Global Pose Estimation using Multi-Sensor Fusion for Outdoor Augmented Reality. In *Proceedings of the 2009 8th IEEE International Symposium on Mixed and Augmented Reality* (pp. 153–162). Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.156.6860&rep=rep1&type=pdf

Schmitz, B., Specht, M., & Klemke, R. (2012). An Analysis of the Educational Potential of Augmented Reality Games for Learning. In M. Specht, J. Multisilta, & M. Sharples (Eds.), *Proceedings of the 11th World Conference on Mobile and Contextual Learning 2012* (pp. 140–147). Retrieved from http://dspace.ou.nl/handle/1820/4790

Sensor. (2017). Retrieved February 8, 2017, from https://www.merriam-webster.com/dictionary/sensor

Sharma, P., Wild, F., Klemke, R., Helin, K., & Azam, T. (2016). *D3.1 Requirement analysis and sensor specifications – First version*. (F. Wild & P. Sharma, Eds.). Internal WEKIT project document, London.

Spatial mapping. (n.d.). Retrieved February 8, 2017, from https://developer.microsoft.com/en-us/windows/holographic/spatial_mapping

Specht, M., Ternier, S., & Greller, W. (2011). Dimensions of Mobile Augmented Reality for Learning: A First Inventory. *Journal of the Research Center for Educational Technology (RCET)*, *7*(1), 117–127. Retrieved from http://rcetj.org/index.php/rcetj/article/viewFile/151/241

Sutherland, I. E. (1968). A head-mounted three dimensional display. In *Proceedings of the December 9-11, 1968, fall joint computer conference, part I* (pp. 757–764). https://doi.org/10.1145/1476589.1476686

Ternier, S., De Vries, F., Börner, D., & Specht, M. (2012). Mobile augmented reality with audio, supporting fieldwork of Cultural Sciences students in Florence. In G. Eleftherakis, M. Hinchey, & M. Holcombe (Eds.), *Software Engineering and Formal Methods - Proceedings of 10th International Conference, SEFM 2012* (pp. 367–379). Springer. Retrieved from http://dspace.ou.nl/handle/1820/5034

Ternier, S., Klemke, R., Kalz, M., van Ulzen, P., & Specht, M. (2012). ARLearn: Augmented reality meets augmented virtuality. *Journal of Universal Computer Science*, *18*(15), 2143–2164. https://doi.org/10.3217/jucs-018-15-2143

VR Intelligence. (2015). *Schell Games CEO, Jesse Schell talks VR and AR in 2016, 2020 and 2025*. [Video file]. Retrieved from https://www.youtube.com/watch?v=wD0bp0r-EpI

Wetzel, R. (2013). A Case for Design Patterns supporting the Development of Mobile Mixed Reality Games. *Foundations of Digital Games*. Retrieved from http://www.fdg2013.org/program/workshops/papers/DPG2013/b6-wetzel.pdf

Wetzel, R., McCall, R., Braun, A.-K., & Broll, W. (2008). Guidelines for Designing Augmented Reality Games. In *Proceedings of the 2008 Conference on Future Play:*

Research, Play, Share (pp. 173–180). Retrieved from http://eprints.lincoln.ac.uk/24599/1/Wetzel et al. - 2008 - Guidelines for designing augmented reality games.pdf

What is WEKIT? (n.d.). Retrieved February 8, 2017, from http://wekit.eu/

White, R. M. (1987). A Sensor Classification Scheme. *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control*, *34*(2), 124–126. Retrieved from http://ijlalhaider.pbworks.com/w/file/fetch/64130986/A Sensor Classification Scheme.pdf

Wild, F. (2016). *User Interaction Design*. Internal WEKIT project document, London.

Xu, Z., Xiang, C., Wen-Hui, W., Ji-Hai, Y., Lantz, V., & Kong-Qiao, W. (2009). Hand Gesture Recognition and Virtual Game Control Based on 3D Accelerometer and EMG Sensors. In *Proceedings of the 14th international conference on Intelligent user interfaces* (pp. 401–406). ACM. Retrieved from https://pdfs.semanticscholar.org/6878/79899cb5c520970fd76eaca8b79e4aee820d.pdf

Yamabe, T., & Nakajima, T. (2013). Playful training with augmented reality games: Case studies towards reality-oriented system design. *Multimedia Tools and Applications*, *62*(1), 259–286. https://doi.org/10.1007/s11042-011-0979-7

You, S., & Neumann, U. (2001). *Fusion of Vision and Gyro Tracking for Robust Augmented Reality Registration*. Retrieved from https://trac.v2.nl/export/5432/andres/Documentation/INS Kalman/fusion of vision and gyro tracking for AR.pdf

Zagal, J. P., Mateas, M., Fernández-Vara, C., Hochhalter, B., & Lichti, N. (2005). Towards an Ontological Language for Game Analysis. In *Proceedings of DiGRA 2005 Conference* (pp. 3–14). Retrieved from https://users.soe.ucsc.edu/~michaelm/publications/zagal-worlds-in-play-2007.pdf

Zhang, Z. (2012). Microsoft Kinect Sensor and Its Effect. *IEEE Multimedia*, *19*(2), 4–10. Retrieved from https://www.researchgate.net/profile/Zhengyou_Zhang/publication/254058710_Microsoft_Kinect_Sensor_and_Its_Effect/links/00b7d53ab783285cdb000000.pdf

Umfrage zum Thema Augmented Reality
* Erforderlich

Allgemeine Daten

1. **Was ist Deine Spezialisierung?** *
   Markieren Sie nur ein Oval.

   ( ) Art

   ( ) Programmierung

   ( ) Sonstiges: _____

2. **Wie viel Erfahrung hast Du in der Spieleentwicklung (Studium mitgerechnet)?** *
   Markieren Sie nur ein Oval.

   ( ) Weniger als 1 Jahr

   ( ) 1 Jahr

   ( ) 2 Jahre

   ( ) 3 Jahre

   ( ) 4 Jahre oder mehr

Augmented Reality - Grundlagen

3. **Kennst du den Begriff Augmented Reality?** *
   Markieren Sie nur ein Oval.

   ( ) Ja

   ( ) Nein   *Weiter mit "Augmented Reality - Definition"*

Augmented Reality - Definition
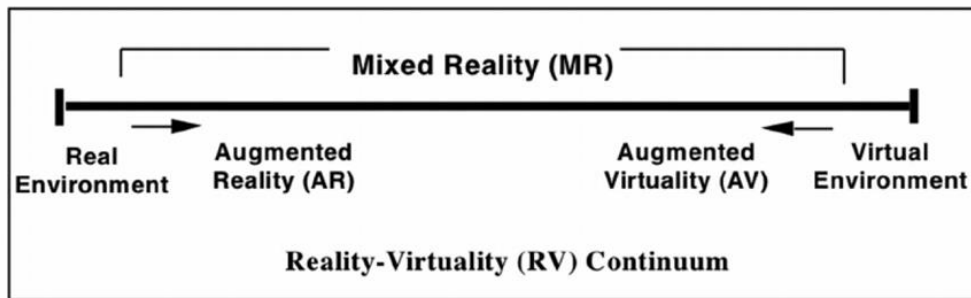
4. **Wie definierst Du Augmented Reality?** *

   _____

Weiter mit Frage 5

Augmented Reality - Definition
Unter Augmented Reality oder AR versteht man für gewöhnlich Anwendungen, die Daten aus der Realität durch virtuelle Elemente ergänzen, beispielsweise indem Zusatzinformationen zum Gesehenen oder normalerweise nicht sichtbare Dinge, wie Stromleitungen, eingeblendet werden. Dies geschieht häufig über HMDs ähnlich Virtual Reality Brillen.

MR-Kontinuum nach Milgram

Mixed Reality (MR)

Real Environment — Augmented Reality (AR) — Augmented Virtuality (AV) — Virtual Environment

Reality-Virtuality (RV) Continuum

Augmented Reality - Expertise

5. **Hast Du bereits Augmented Reality Anwendungen verwendet? ***
   Markieren Sie nur ein Oval.

   ( ) Nein, ich habe kein Interesse daran

   ( ) Nein, aber ich habe Interesse daran

   ( ) Ja, einmal

   ( ) Ja, mehrfach

   ( ) Ja, regelmäßig

6. **Wenn ja, welche?**

   ....

7. **Hast Du bereits Augmented Reality Anwendungen entwickelt? ***
   Markieren Sie nur ein Oval.

   ( ) Nein, ich habe kein Interesse daran

   ( ) Nein, aber ich habe Interesse daran

   ( ) Ja, einmal

   ( ) Ja, mehrfach

8. **Wenn ja, welche?**

   ....

Augmented Reality - Zukunft

Bewerte die folgenden Aussagen

9. **Augmented Reality Games werden zukünftig ein wichtiger Bereich der Gamesindustrie sein. ***
   Markieren Sie nur ein Oval.

	1	2	3	4	5	
Stimme nicht zu	( )	( )	( )	( )	( )	Stimme zu

10. **Bitte begründe diese Antwort**

11. **Augmented Reality Games werden zukünftig ein wichtiger Bereich in der Bildung sein.** *
Markieren Sie nur ein Oval.

	1	2	3	4	5	
Stimme nicht zu	◯	◯	◯	◯	◯	Stimme zu

12. **Bitte begründe diese Antwort**

13. **Die Verwendung zusätzlicher Sensordaten, insbesondere über den Benutzer (Bewegungsdaten, Body posture), kann AR Anwendungen verbessern.** *
Markieren Sie nur ein Oval.

	1	2	3	4	5	
Stimme nicht zu	◯	◯	◯	◯	◯	Stimme zu

14. **Bitte begründe diese Antwort**

15. **Wenn ja, wie könnten Sensordaten verwendet werden, um Augmented Reality Erfahrungen zu verbessern?**

16. **Was für Arten von Sensoren könnten sich zur Verbesserung von AR Anwendungen besonders eignen?**

Danke für deine Teilnahme an der Umfrage

17. **Feeback zur Umfrage**

7 Declaration of authenticity

I, the undersigned, declare that all material presented in this bachelor thesis is my own work or fully and specifically acknowledged wherever adapted from other sources.

I understand that if at any time it is shown that I have significantly misrepresented material presented here, any degree or credits awarded to me on the basis of that material may be revoked.

I declare that all statements and information contained herein are true, correct and accurate to the best of my knowledge and belief.

Felix Emmerich
09th February, 2017