Julia Birgit Viehberger, BA BsC

Designing Human-Centered Information Services for Production

Master's Thesis

to achieve the university degree of

Master of Science

submitted to

Graz University of Technology

Supervisor

Ass.Prof. Dipl.-Ing. Dr.techn. Wolfgang Vorraber

Institute of Engineering and Business Informatics
Head: Univ.-Prof. Dipl-Ing. Dr.techn. Siegfried Vössner

Graz, December 2018

Affidavit

I declare that I have authored this thesis independently, that I have not used other than the declared sources/resources, and that I have explicitly indicated all material which has been quoted either literally or by content from the sources used. The text document uploaded to TUGRAZonline is identical to the present master‘s thesis.

Date

Signature

Abstract

Technology is changing in a faster and faster way in the recent years. The innovation cycles are becoming shorter, so planning, developing and releasing new software can happen simultaneously. That leads to a higher need to look at the impacts and possible consequences of emerging technologies. Responsible Research and Innovation is an approach for a more responsible and sustainable development process, which also focuses on societal inclusion and dissemination of results.

Despite the overall impacts of technology, especially communication and collaboration were changed due to innovations. Computer Supported Collaborative Work examines these effects in technology-supported working environments.

Both topics, Responsible Research and Innovation and Computer Supported Collaborative Work were covered in the theoretical part of the present master's thesis to provide an overview. As a next step, they were applied at the use case in order to provide a link between the practical and theoretical part.

The aim for the practical part was to implement an Augmented Reality app for the workshop of the Technical University. The main function of the app is the detection of possible collisions in milling machines to prevent tool breakage. Therefor the app provides a runtime import of 3D models of components and lets the user rotate and move a virtual component along all three axes.

In conclusion, the results of the development process and practical tests are presented and a future outlook is given.

Contents

List of Figures

1. Introduction

In the recent years, a huge shift in technology took place all over the world. On the one hand, different hardware was developed, which supports and also influences the society in their daily lives and makes different Internet applications more accessible. On the other hand, there is the software dimension, where a wide diversification in applications arose. That technological progress enables people to be connected all the time and be supported by different applications in daily life situations. These changes lead to a higher need of questioning the impacts of such changes to society.
Therefor Responsible Research and Innovation (RRI) is a relatively new approach which is targeting to have a deeper look on responsibility and moral values during development. It searches for inclusion of the society to gain better insights, what people think about new development strategies, but also tries to open up the results of conducted research activities to wider public, that people can see the outcome. Furthermore it brings in the gender aspect to achieve a better distribution of men and women in research processes and to accomplish more significant and representative outcomes. The strategy of Responsible Research and Innovation goes also in the direction of responsiveness to react directly to the given feedback of citizens. Beside that self-reflection plays an important role. It is an enhancement to mirror somebodies own activities and influences during the research process. With all that strategies Responsible Research and innovation tries to accomplish a participative and socially desirable way of research.
Beside that, Computer Supported Collaborative Work (CSCW) examines the collaboration between people which are supported by technical devices. In the last decades, for one thing the communication of the society was increasing in general, because much more information was needed, then again the exchange of information changed. People have to collaborate over distance, which can only be achieved with modern communication tools.
Technological support is not only necessary for communication, though

it was one of the first research items of CSCW. It can enhance various industry fields for daily work processes. Therefore Augmented Reality (AR) comes into focus. Since the Pokemon GO hype in 2016, the popularity of Augmented Reality increased. That technology enables to overlay particular spots with different content. As in Pokemon GO it can be used for a game, but the more important aspect - it can support different work tasks, for example with tutorials, navigational aid, comparison methods or virtual experiments or try outs.
As already raised before, the following thesis will focus on the topics Responsible Research and Innovation, Computer Supported Collaborative Working and Augmented Reality. It will start with describing the concept of RRI in the first section and outlining different approaches for conducting RRI, followed by frameworks how to apply it.
The second part contains the concept of Computer Supported Collaborative Working, which will focus on its classification for interaction methods and afterwards it tries to establish the connection between AR and CSCW with analyzing different existing AR applications which support the collaboration of people.
Augmented Reality will start with some theoretical facts about frameworks, detection methods and devices, before dealing with the practical implementation of AR. The practical part of the thesis is based on a project, which emerged from a cooperation with the Institute for Production Engineering of the Technical University in Graz. In Production Technology various machines have different sized working spaces, so when processing components, that has to be considered as good as possible. In some rare cases in individual production, collisions can occur, which lead to tool breakage. For such incidents, a methodology is needed to prove it beforehand. That is possible with Augmented Reality by processing a virtual component beforehand. So that topic became the practical project of this Master's Thesis.
For that use case, the implementation process is outlined and different used frameworks are explained.
Finally, all concepts are discussed and a future outlook will be given.

2. Responsible Research and Innovation

In the last years technology was changing in a fast pace and a huge number of different applications have been developed. The society is using different applications more frequently and they are supported by technology in many situations. That leads to a higher need of questioning the impacts of these changes.
Therefor Responsible Research and Innovation is a relatively new approach which is targeting to have a deeper look on responsibility and moral values during development. It sets itself the *"challenge of designing innovations in a socially desirable and acceptable way."* (Jirotka et al., 2017, p. 1). That means to go beyond the purposes of a project and try to figure out the right impacts and social or ethical values of a project, which goes along with the role of responsibility for creating new products. (Owen, Macnaghten, and Stilgoe, 2012)
Specifically, that means to provide regulations or certifications, which help the society to achieve usage in a fair manner. An example for the Information and Communication Technology (ICT) area, where ethical concerns arise, is social media. Social media became more popular in the last years and people can share different content such as postings, pictures, links and many other stuff with other people. People have the freedom to post, whatever they want. When social media platforms have been established, there were less concerns that shared content can be problematic. In the last years, practice has shown, that rumors and false information are posted on different media platforms and are redistributed in a fast pace without proving the validity of the original source. That phenomenon of the rapid spread of unverified content is called "digital wildfire". It reaches a higher number of people much faster than word of mouth or common newspaper

articles. The propagation of false information can cause considerable harm, e.g. rumors about groups can lead to stronger tension between them. Such effects show the need of ethical considerations of social networks. (Webb et al., 2016) For example, in the riots of 2011 in the UK, the government called for social media clampdown. In such cases, also the shutdown of social media was contemplated. (Halliday and Garside, 2011)
In general, such extreme cases are rare, but there is still a need for regulation in social networks. Several countries have rules in their terms and conditions, what can be posted online and what is forbidden. These regulations depend on the country itself as some countries have stricter rules. Although there are terms, they are not enforced that strong, which had also been criticized. As a reaction, the companies invented a "report"-button to have kind of a self governance and include people to participate in detecting rumor content. The restrictions of content in social media posts lead also to discussions about the freedom of speech. Therefor pros and cons need to be judged to get closer to a solution. (Webb et al., 2016)
In industry, product certificates reached a rising popularity. For example labels such as fairtrade, free from animal testing, natural cosmetics and similar ones provide information for the customer, that the product was produced with respecting special values. On the other hand, it facilitates the purchase decisions to refuse other products. Several websites provide information about which product has which labels. (Gurzawska, Mäkinen, and Brey, 2017)
The following chapter starts with a brief overview of the history of RRI, more specifically its predecessors: Computer Ethics and Codes of Conduct. Furthermore it provides a definition of RRI and then it discusses application areas in general before focusing on ICT. It concludes with a classification of RRI processes and afterwards it provides concrete tools for RRI, both general and specialized tools for ICT.

2.1. Early Responsible Development

Before RRI was developed, there was a more general research and analysis to discuss the topic of a considerate development in an ethical manner. There were currents of bringing ethics into the ICT section, which was called

"Computer Ethics". On the other hand, organizations in the Information and Communication Technology started to develop guidelines for professional collaboration, called "Code of Conduct". The following chapter will provide in-depth information about both topics.

2.1.1. Computer Ethics

Computer Ethics started to develop in the 1950s with general concerns, but the most research has been done in the 1980s and 1990s. The topic had its roots in computer science and philosophy and started with concerns such as what is good or bad, right or wrong. That included rational decision making in case of a dilemma and the start of considering the individual character. Beside that it looks at the change of the social interaction and the behaviour with the use of technology. The second concern can be seen as meta-level, what means that computers create moral problems, which didn't exist before. (Stahl, Eden, Jirotka, and Coeckelbergh, 2014)(Jirotka et al., 2017)(Spiekermann, 2015)
Later on more concrete topics emerged from discussions, as the *"the fields of personal identity, changes to the social sphere, political participation and citizenship, and the sphere of e- commerce."*(Stahl, Eden, Jirotka, and Coeckelbergh, 2014, p. 812) Debates were also held on political level. In those days, privacy became already a dominant topic of discussion, because of the issue of how data gets processed and stored. That led to the occurrence of the *"tension between individual rights and national security."*(Stahl, Eden, Jirotka, and Coeckelbergh, 2014, p. 812) In concrete, the tension was between privacy and security, because security can be a problem of the power relation.
Another subject was the ownership of intellectual property and software in general. Copying things in the Internet and piracy is considered as theft in general. But in that case, lots of people don't see it as theft and for them it is even acceptable, because it is not stealing any kind of physical object, it is only virtual. But that doesn't mean, copying things doesn't harm anybody. If people are copying movies or music, less CDs or DVDs are sold, which harms the music and film business. Principally, it can be said, that things are not automatically acceptable, just because the majority of people think so.

Moreover identity theft can be performed online much easier. It requires less effort to pose as someone else because of the anonymity. There is the urgency to gain protection against that kind of crime.
Freedom of speech belongs to the fundamental rights of humankind, but in the Internet it must be seen a little bit narrower. In some way, censorship and moderation are necessary, because freedom of speech would harm other people. (Stahl, Eden, Jirotka, and Coeckelbergh, 2014)

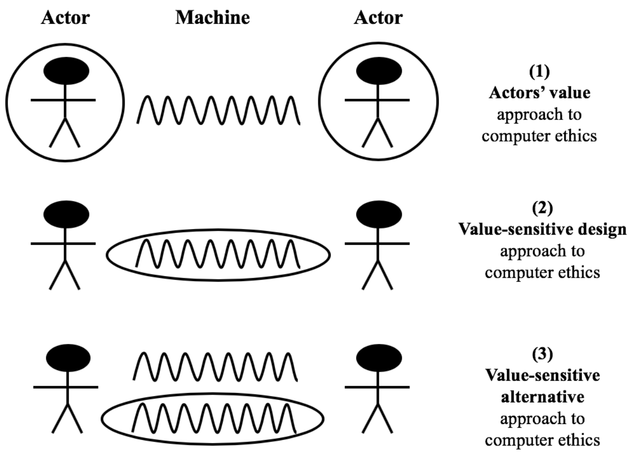

Figure 2.1.: Three major discourses in ethics (Spiekermann, 2015)

When dealing with practical issues like those ones mentioned before, concrete methods and discourses are needed as a base for reflection. In computer ethics, three major discourses exist, which have different opinions of the interaction between the machine and the user. Figure 2.1 will give an overview about them, followed by an explanation below. Afterwards the focus will be on discourse number two, which deals with value-sensitive design.

Spiekermann(Spiekermann, 2015) suggested the following three major discourses in ethics:

1. The machine is given and the focus is on the actor using the machine.

2. Value-sensitive design: The machine is not given, instead it can be shaped to user needs and values.
3. Alternative to value sensitive design: Scientists should go beyond value-sensitive design and search radically for ways including new technologies to create the same customer value.

Value-sensitive design is a technique, which has its roots in ethics, but it is also used in other disciplines like Human Computer Interaction (HCI) and RRI. Values serve as a base for the design of the machine. A four step guide was developed from Spiekermann(Spiekermann, 2015), which is explained below and shown in Figure 2.2:

1. **Value discovery** is the basic research about benefits and threats for affected persons, which are transformed into values. It is reviewed, if there are differences of threats or benefits in the context and also if that leads to a change in the importance of the values. The outcome is an initial set of values.
2. **Value conceptualization:** The values are examined and split into several parts. In that stage it is necessary to check for conflicts between values. The outcomes are well defined values.
3. **Empirical value investigation:** Values are prioritized in groups of stakeholders and a voting takes place. Before these votes, boundaries are defined, which percentage of the voting result would change a special opinion or lead to a decision. The outcomes are detailed prioritized values, which are translated into development goals.
4. **Technical value investigation**: Development goals are translated into a technical specification. The outcome of that stage is a reasonable technical design, where value conflicts are eliminated.

Limitations

Computer Ethics also has some limitations, which request for new approaches and further developments. First, it is more limited to the word 'computer' as a physical thing, whereby non-visible things or computer-similar things are excluded. Cars, washing machines, vacuum cleaner robots and many other appliances are controlled by a tiny computer, which is not taken into account in a reasonable scope.

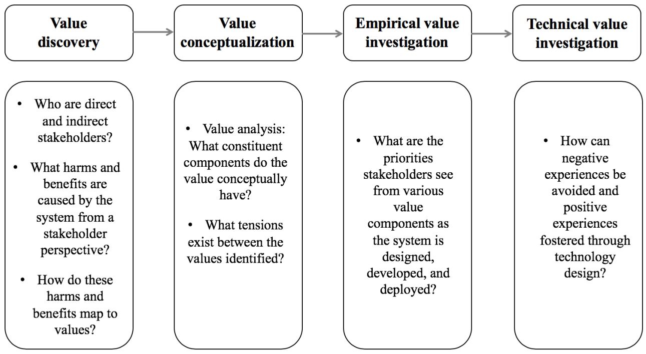

Figure 2.2.: Value-sensitive design(Spiekermann, 2015)

Principally ethics is a more reflective and conceptual work and it contains less empirical research, because of philosophy. Discussions are held more general and not substantiated to a subproblem, where side effects can be reflected as well. Ethical review processes don't address broader concerns, as for example the societal consequences of innovation. That led to advancements, which focus better on current problems. (Stahl, Eden, Jirotka, and Coeckelbergh, 2014)(Jirotka et al., 2017)

2.1.2. Code of Conduct

In the 1960s, when there was a growing interest in Information Technology, also ethical concerns for the collaboration within a company occurred. People in organizations started to develop guidelines for professional collaboration within the organization and for public work. Therefor ACM, IEEE and BCS developed their own ethical guidelines - called "Code of Conduct", which have been refined over time and adjusted to the actual state-of-the-art. A Code of Conduct is a set of rules for members of an organization, which contains norms, regulations and practices. It serves as a basis for a constructive innovation process and encourages the knowledge exchange. (Schomberg, 2013)
Beside that the Code of Conduct should also help with policy development. Policy development is always complicated, because the feedback of governments has to be at the right time. If it is too late, it can happen, that there is

no possibility for interventions left. In case it is too early, there is too less research available to give adequate feedback. Therefor governance should be designed with flexibility. All in all, the Code of Conduct can be seen as a professional guideline for participants on how to deal with several issues. (Schomberg, 2013)
The following section will describe the Codes of Conduct of ACM, IEEE and BCS and also their development. Conclusively a short comparison of all three codes is provided.

ACM

In 1966 ACM published the "Guidelines for Professional Conduct in Information Processing", which is a predecessor of the "Code of Ethics". It consisted of relations with the public, employers or clients and other professionals. That part containing the public relations has one statement, which is going into the ethical direction: *"An ACM member will have proper regard for the health, privacy, safety and general welfare of the public in the performance of his professional duties."*(ACM, 1966)
In 1972, the guidelines have been revised and classified into ethical and disciplinary rules. Also these guidelines were kept quite universal and not that specific for computer science. (ACM, 1972)
The 3rd version was published in 1992 and renamed to "ACM Code of Ethics and Professional Conduct". This version has been completely revised and adapted to actual concerns in the ICT field. As in the early 1990s computer ethics and moral values gained more interest for professionals, that was also incorporated into the code. A whole section is about general moral values. (ACM, 1992)
At the moment, ACM is working on a new version of their code. The drafts have already been published and are available at the moment for discussion, before the new version will be published officially. (ACM, 2018)

IEEE

IEEE published its own Code of Ethics, which was developed in 1963. (IEEE, 1963) In comparison to ACM, their ethical and professional code is kept brief. It contains ten standards, which are dealing with avoiding injuries or conflicts, assist colleagues or reject bribery. Same as for the ACMs guidelines, the first standard relates to the public safety and moral. The community should *"hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices, and to disclose promptly factors that might endanger the public or the environment."* IEEE sees it as an objective, that people who act on behalf of the organization should also comply with the standards. (IEEE, 2018)

BCS

The British Computer Society (BCS) provides also a Code of Conduct, which was released in 2006. But it was not the first document about ethical concerns of BCS. The predecessor was the 'Code of Practice' of 1978, which contained four sections: personal requirements, organization and management, contracting and privacy, security and integrity. (BCS, 1978)
The new Code of Conduct consists also of four main sections. The sections are now called public interest, professional competence, duty to relevant authority and duty to the profession. Public interest is about the wellbeing of others and the environment, against discrimination because of special characteristics and *"to promote equal access to the benefits of IT"*. (BCS, 2015) The second section describes issues directly related to somebodies own work and competences. People should work on topics, which they are qualified for. It should not exceed their competences in that sense, that they claim knowledge, they don't possess. Criticism and other viewpoints should be accepted and cherished. Bribery and other unethical attitude should be rejected. Duties to relevant authorities contain the prevention of conflicts of interest with them and also not to *"take advantage of the lack of knowledge or inexperience of others."* (BCS, 2015) Section four describes the professional collaboration, as for example supporting other members, improve the professional standards and do not harm the reputation of BCS. (BCS, 2015)

Comparison of Ethical Guidelines

The sections before provided a short overview about three well-known Codes of Conduct. All three can be found in detail at the particular website of the organization, where also a little bit of history is provided. As it can be seen in the summary, all three different versions refer to the same or at least very similar ethical concerns. All of them consider in the first section the public - health, safety, welfare, human well-being, privacy, security. What goes along with this standard is the prevention of discriminating people because of race, religion, age, origin, disability, gender and many more, which is covered by all codes. Additionally BCS and IEEE deal with the subject of bribery. While IEEE only suggests to reject bribery, BCS also talks about other unethical inducement and that it should be rejected and not offered to anybody. Another interesting point is the feedback topic. BCS addresses that point a little bit in the last section with *"encourage and support fellow members in their professional development."* (BCS, 2015) In general BCS suggests to accept criticism, while IEEE and ACM also recommended to offer feedback to others and to promote the assistance between colleagues. (BCS, 2015)(ACM, 1992)(IEEE, 1963)
All in all, the three Codes of Conduct are very similar, most of the time only the formulation differs in accuracy and length. That leads to slight differences in the rules.

2.2. Responsible Research and Innovation

After having a short introduction about the research streams which served as predecessors for RRI, the focus will switch to RRI itself. It starts with early research activities in RRI, which were independent of one another. Afterwards a definition and a fundamental explanation are provided before focusing on application areas in general and particularly in ICT.

2.2.1. Emergence of RRI

Responsible Research and Innovation is a relatively new concept developed from 2000s on. It was mentioned first by Hellström in 2003 (Hellström, 2003) and by NNI as 'responsible development' 2004. (NNI, 2004) Hellströms approach addresses technological systems in general and describes the issue more as risk assessment, where challenges are in the sections technology, infrastructure and society. His solution includes two parts: risk reduction and responsible innovation. Risk reduction consists of *"identifying critical systemic nodes"* (Hellström, 2003, p. 380) and *"creating slack or buffers that may absorb disturbance affecting these nodes"* (Hellström, 2003, p. 380). Hellströms understanding of RRI is creating new design principles for work, which provide a greater foresight about consequences across society, e.g. if new technologies are invented or for extensions of existing technologies. These impacts on civilization call for societal participation, because public acceptance gains more and more importance. (Hellström, 2003)
The National Nanotechnology Initiative (NNI) provided a strategic plan for Nanotechnology in 2004, which included the term 'responsible development'. Responsible Development means to include societal dimensions when inventing new technologies. For Nanotechnology, these are *"the access to benefits arising from Nanotechnology, effects on the labor pool, changes in the way medicine is practiced, the impact of manufacturing locally at the point of need, concerns regarding possible health or environmental effects, and privacy concerns arising from distributed nanotechnology-based sensors."* (NNI, 2004, p. 24) For one thing, the collaboration with the public is providing the information to them, then again NNI is seeking input from them. That is the base for well-informed decisions and trust among different stakeholders.
These two projects were the pioneers in the field, which laid the foundation for RRI. In the 2010s a big progress has been done with Horizon 2020 - EU Framework Programme for Research and Innovation. It is the biggest EU - and even worldwide - Research and Innovation program lasting from 2014 to 2020, which is open to everyone. It is a funding authority, which helps people to start with projects faster, what leads to prompter results. The main three goals are excellent science, industrial leadership and tackling societal challenges. In general the work program consists of nine sections, beside the three main goals, it covers also "Science with and for Society", which

encompasses the topic Responsible Research and Innovation. Within that project the societal challenges - denoted as grand challenges of our time - have been developed. They serve as a basis for many research projects in RRI and address major concerns by European citizens. That includes climate change & resource efficiency, food security & water research, health & aging population, security & freedom, transport & energy issues. (Owen, Macnaghten, and Stilgoe, 2012) (Horizon2020, 2014) (FFG, 2011)

2.2.2. Definition and Essentials

RRI is not an universal definition, what can be seen as responsible - or what is good, right, desirable and morally correct - it is a whole process of addressing the issues arising with new technologies. It can be seen as a higher level or meta responsibility, which helps to identify the potential impacts that technical innovations can have on somebodies life. Emerging technologies need control on the one hand and involvement of society on the other hand. Control is basically given by legal requirements, but it needs to be refined by the company itself depending on the product. The involvement of society helps to overcome the challenges of socially desirable and acceptable products and to reduce uncertainties. (Stahl, Eden, and Jirotka, 2013) (Jirotka et al., 2017) (Owen, Macnaghten, and Stilgoe, 2012) (Schomberg, 2013)
Von Schomberg also tried to suggest a definition of RRI: *"Responsible Research and Innovation is a transparent, interactive process by which societal actors and innovators become mutually responsive to each other with a view on the (ethical) acceptability, sustainability and societal desirability of the innovation process and its marketable products (in order to allow a proper embedding of scientific and technological advances in our society)"* (Schomberg, 2013, p. 19)

As the name already indicates, RRI denotes responsive and anticipated research. Researchers have to think about the right impacts for innovation and to take the *"grand challenges of our time"*(Schomberg, 2013, p. 1) into their mind. It is necessary to become adaptive to them and to prioritize targets. Therefor growth should be decoupled from environmental inputs. That helps to get a better foresight for new technologies and to define

own research priorities, which go beyond market benefits and risks. (Owen, Macnaghten, and Stilgoe, 2012) (Schomberg, 2013)
As the outcomes are usually for society, the people dimension should be taken into account, because *"Innovation is beneficial to people only if it meets the needs of society, providing economic, environmental and social sustainability."*(Burget, Bardone, and Pedaste, 2017, p. 3) Therefor the best approach to avoid irresponsible behaviour are early societal interventions. Society belongs to the group of stakeholder as well and stakeholders are not only from business department anymore. Such mixed groups provide important information for development processes. That helps to prevent, that technologies are failing. (Schomberg, 2013) (Eden, Jirotka, and Stahl, 2013)
Societal interventions are indispensable for RRI, but also the creation of public interest for science is an important process. Generally the connection of tech, society and science can help for a better acceptance. (Eden, Jirotka, and Stahl, 2013)(Stahl, Eden, and Jirotka, 2013)

Beside society, control and the product itself needs to be analyzed. In this context, RRI examines the ethical and correct behaviour of a product. That means, that the provided functions of a product are working and don't lead to any misbehavior, which can harm people using it. Then again users should not be able to use functions in a malicious way. In addition to a companies responsibility, the state itself has an obligation to care about risk management and product regulation. Product liability is regulated by law and the state is also responsible for the product authorization. Products are verified by product tests to check if they are safe. For the acceptability of products the society dimension plays an important role again. Products have to fulfill the needs of society. In the end they decide with their purchase behavior, if they accept a product. (Schomberg, 2013) (Owen, Macnaghten, and Stilgoe, 2012)

As Hellström already mentioned the risk factor - which was explained in section 2.2.1 - in 2004, it is still a valid concern. Risk occurs with the use of new technology. At the development period it is hard to predict, if a product or a new technology will be accepted or declined, because there is too less information available. If the project is almost finished, it would be easier to forecast the future prospects, but it is much more difficult to intervene. Though the attempt is to manage potential risks beforehand, there is a need to think about possible impacts in all stages of a project. As in projects the time period when to conduct RRI differs, a categorization of activities for industry has been provided by Jirotka et al. (Eden, Jirotka, and Stahl, 2013) (Stahl, Eden, and Jirotka, 2013) Three main sectors of activities for industry:

- **Upstream** describes the start period of a project which contains for example proposal writing.
- **Midstream** tasks are design activities which take place during the project or research.
- **Downstream** activities are scheduled after the development, when the product is already created. (Eden, Jirotka, and Stahl, 2013)

With a responsible and more interactive innovation process, the rejection of technologies and products can be decreased or avoided. But that is only a superficial application and explanation of RRI, to get an idea, what it actually is. After having a short look on irresponsible innovation, the following section will deal with the application of RRI in industry and ICT. (Schomberg, 2013)

2.2.3. Four Types of Irresponsible Innovation

The section before gave a review, what can be described as responsible behaviour. On the contrary also irresponsible behaviour exists. It is important to cover also these practices to avoid such behaviour. Van Schomberg (Schomberg, 2013) tried to define the following four categories of irresponsible behaviour.

- **Technology push** is a radical innovation in a particular sector, which can lead to a high yield but also implies a high risk. A famous example is the genetically modified soy in the 1990s of Monsato. Several NGOs and European governments called for stricter regulations for GMOs (gen-technical modified organisms). Discrepancy occurred between the stakeholders and in the mind of NGOs, the regulations were only about safety and excluded the environmental, agricultural and social aspects.
- **Neglect of fundamental unethical principles:** In the ICT area, an important concern in this section is privacy. Privacy issues or other

ethical concerns should be dealt with in early stages and not in a late phase of the project, where almost everything has already been implemented. Important scenarios to think of are on the one hand the question of the ownership of data and on the other hand about the person in charge for mistakes.

- **Policy pull** has occurred in security technologies, such as body scanners or biometrics for passports. Policy makers were promoting technologies with too less thoughts about the feasibility and reasonableness of introduction. For body scanners, even the implementation was stopped by the European Parliament due to its disproportion. After a terrorist boarding on an airplane, the introduction seemed reasonable. The European Parliament set a few requirements for the introduction at the end. Passengers are not obligated to use it and instead of pictures, the scanner makes representations of the body, which are not stored in a database. As shown in that case, requirements arise from the market and need to be evaluated. Though there is always the question, where is the distinction of acceptable infringements of privacy and risks.
- **Lack of precautionary measures and technology foresight:** Sometimes precautionary measures are missing during the development or market introduction of a new product. Scientific uncertainty and scientific ignorance led to bad decisions, which cause harm to people. In case of uncertainty, alternative research or development trajectories should be considered.

2.2.4. RRI Applications

RRI can be conducted in many different research fields. As already mentioned before, the beginnings of RRI took place in Nanotechnology. Later on it was also applied in environmental and health sciences, geo engineering, genetically modified organisms, industry, synthetic biology and ICT. (Jirotka et al., 2017) (Owen, Macnaghten, and Stilgoe, 2012)
The following chapter will describe the application of RRI for industry and ICT. That description will provide an overview of how different the scope of application is in different research fields.

RRI in Industry

As in almost all research fields, RRI for industry was not created out of anything. In that case the predecessors were business ethics and Corporate Social Responsibility (CSR). Ethics was already outlined in section 2.1.1 and is a more theoretical and general approach. Corporate Social Responsibility is a famous concept, which addresses a company's responsibility towards the society. That can be saving energy during production, workplace conditions or workers rights. It is a basic concept, which can be used together with RRI. (Martinuzzi et al., 2018)(Gurzawska, Mäkinen, and Brey, 2017)
RRI in industry and especially CSR go more in the direction of investment and its influence. Investment and its outcome are described as a loop. At first, the company invests into business tools, processes, employer education and other goodies. That usually leads to a higher motivation and engagement, what results in a higher productivity. The effect is a higher profit, which can be used for investment again. (Gurzawska, Mäkinen, and Brey, 2017)
When it comes to RRI in industry, a well-known example are labels and certifications. In the recent years customers look more and more for ethical and eco-friendly products and labels have raised a broader interest for society. People know labels and make more informed decisions. Several websites rate companies in different categories of how responsible they produce. People can search for products, which comply with their values. That is an indirect call for companies to set standards. Certification by 3rd parties create trust and also companies can choose business partners with the same interests and values. Although there are lots of advantages, also some problems arise with that concept. For small companies the costs for the certification can be a problem as well as bureaucracy can be a hurdle. Another difficulty is the jungle of different labels. Competing labels lead to uncertainty and the information for customers is lost. Another phenomenon is "greenwashing", which means, that the company doesn't care much about the environment, but they convey a much better image of their company. All in all the majority of people only refuses products, if there was a scandal or if they were negatively present in the media. That fact can be seen as a reminder for reviews, that things will be changed, before being negatively

present in the media. Beside the media and customers, also NGOs have an influence, because they inform people, so they can judge fast. The fast spread of information can be also a risk for a company. (Gurzawska, Mäkinen, and Brey, 2017)
The former paragraph focused on labels in industry for concrete products, but that is not the single application area. For software systems labels also gained more importance in the last years. A famous example for online shops is the label "TrustedShops". It offers buyers protection and reviews from real customers. Beside that, it demands a particular level of service from the online shop and *TrustedShops* also offers a customer care department for further requests.

Apart from labels, in industry it is also important to include the society into the research process considering that people are the end-users of the product. In industry, the focus is more on the production level instead of the research level, so in that case a tension between the advantages and costs of further analysis occur. Advantages are the creation of a product, which fits better to a users needs and what also results in a higher profit and moreover the image of the company is better. The disadvantage is the cost factor. RRI interventions call for a stakeholder participation and are time-consuming. In that case, companies need to find a balance between costs and benefits. (Martinuzzi et al., 2018)

As in all industry fields, RRI should start at CEOs level, but should also be applied on other management levels. Especially in classic companies creating physical products, it is more important, because the products pass by a lot of employees. In that case project or line managers are supposed to be a role-model. Their task is to integrate RRI and ethical principles in the business culture, so that employees can take over these values and work responsible. (Gurzawska, Mäkinen, and Brey, 2017)

RRI for Information & Communication Technology

Technology is transforming the world, so developers are asked how it is influencing the society in long term. Therefor many things need to be considered and new challenges arise. There is the question of how to deal with crowd sourced information or morally incorrect assignments, the coordination of events, with privacy issues like data protection for example in social networks and also how to prevent computer crime or how free expression can be managed. In the context of free expression, issues arise with moderation of content. In some case, moderation is needed to prevent the spread of wrong content like fake news or cyber-bullying, which limits the free expression. (Stahl, Eden, and Jirotka, 2013)(Eden, Jirotka, and Stahl, 2013)(Webb et al., 2016)

In the 1980s David Collingridge tried to find an explanation for the complex situation with the control of technology, which is actually called 'dilemma of control'. It describes the problem, that in early stages, there is too less information to discuss possible consequences and to steer something in a special direction. Later on, when there is enough knowledge and the technology is already embedded in society, people know, what to change, but there is too less power to do so, because it is already accepted and used. (Liebert and J. C. Schmidt, 2010) Also the discussion of applied and fundamental research goes in that direction. Scientists, who do fundamental research have mostly the concurring opinion, that their research is too far away from usage to think about the consequences. So there are actually less concerns than in applied research.
To decrease Collingridge's slightly pessimistic way of control, new methods are required, which already take place in Requirements Engineering (RE). Scenario analysis, risk assessments, stage gating or technology impact assessments can be applied already in RE. Another method are the three levels of engagement, where at *"first, through the development of high-level strategy within the funding council; second, greater reflective practice in the peer review process; and third, at a project level using participatory design devices such as facilitated workshops."*(Eden, Jirotka, and Stahl, 2013, p. 4)

Beside the dilemma of control, there are many other moral challenges to solve. A frequently asked question in ICT is "who is responsible" and it is hard to answer. Most of the time, especially in the ICT area, many people work on a project and everybody is touching a special piece of it. Every participant works responsible in his/her part of the project, but with more participants it is getting complicated. All parts of the project are merged

from time to time and in the collection negative consequences can arise. The interaction and coupling of components is complex and can lead to irresponsible behaviour. (Schomberg, 2013) (Stilgoe, Owen, and Macnaghten, 2013)
Moreover RRI starts much earlier in the software life cycle. It should involve the development process and the behaviour in the team. A product has to be developed in a specified quality and delivered on time. The functionality must be given, the usability must be considered, as for example a fair treatment of users. At that period, existing regulations like data protection or copy right should be regarded. In the team itself most of the time a code of conduct exists, which regulates the collaboration of actors like the transparency of code. A teamleader has to ensure the responsible behaviour of all her/his team members. (Stahl, Eden, and Jirotka, 2013)
Another challenge is autonomous technology, for example automatic reasoning, which means that machines have to make moral decisions in emergency situations. People have to trust the machine, although misinterpretation can happen for instance with object recognition.
A quite interesting concern in the sense of autonomous technology is also the human-robot-interaction. In that case scientists have to consider the desired behaviour of robots in a certain context, that people will accept it, which leads also to the question, if people have the same expectations of the behaviour or if it is completely different. (Eden, Jirotka, and Stahl, 2013) (Stahl, Eden, and Jirotka, 2013)
Over time new methods were invented to cope with that issues. A relatively new and fresh approach is privacy by design. It relates to the new DSGVO from May 2018. Generally it means, that data protection can be complied easier, if it is already considered at the time of the technical implementation of data processing. (Eden, Jirotka, and Stahl, 2013) (Stahl, Eden, and Jirotka, 2013)

In conclusion a lot of approaches have been invented to handle these challenges, but still new ones arise with new technology. In general one can say, that in short term RRI sets its focus on projects and in long term, the grand challenges are addressed. (Eden, Jirotka, and Stahl, 2013)

2.3. Classifications of RRI

Since RRI was taken more into account during research, several classifications have been proposed to provide a simple basis for the practical work. A basic knowledge is necessary to apply concrete strategies and frameworks such as in the subsequent section. The following section will start with the six EU dimensions as a general approach, continue with the four P's of Jirotka and finish with a classification of Stilgoe, whereby both are specialized in technology, especially the ICT area.

2.3.1. The six EU-Dimensions

The Directorate-General for Research and Innovation of the European Commission defined six dimensions for RRI in 2012, namely Engagement, Gender Equality, Science Education, Open Science, Ethics and Governance. Engagement describes the public participation at research, Gender Equality means that women and men are on board at a project. Science Education is about the availability of knowledge to everyone, while Open Science means to make the results accessible. Ethics ensures, that innovation doesn't dispute with moral or fundamental values. Governance unites the first five dimensions and stands for transparency and accountability in research. (EuropeanCommission, 2012)(Gurzawska, Mäkinen, and Brey, 2017)

The following list will address the six dimensions in detail:

- **Engagement**: Public engagement describes the involvement of further stakeholders in the research process. That participation helps to gain new insights, other views to problems or alternative solutions which leads to a democratization of technological evolution. Engagement is not only a term for citizen participation, it describes different methods of involvement. For example a stakeholder can be an interest representative, but it can also be a layperson, which is usually not included into any research processes. A layperson is an expert in a particular topic, that is present in his/her living environment. Participation includes information, inclusion, involvement, contribution and to take part in decision-making. The goal is to inform people, get feedback after proposed solutions or analyses, the collaboration with the public within a process, the corporate elaboration of solutions and alternatives and last but not least the decision-finding process. That should help to create openness and awareness of technical innovations. (RRI-Plattform-Österreich, 2016)(EuropeanCommission, 2012)

- **Gender Equality** is based on the experiences for inclusion into processes of Gender Mainstreaming. It is divided into two main sections: the research process and the content of the research. In the research process, the proportion of women need to be increased to reach a better balance of gender. That helps to get more different insights into topics. The second dimension - the content of the research - addresses the problem of unilateral results. Research also needs female test persons for studies to make it representative. (RRI-Plattform-Österreich, 2016) (EuropeanCommission, 2012)
- **Science Education:** The European Commission promotes the natural sciences especially for young people. That should help to have informed citizen on the one hand and maybe arouse interest to become a scientist on the other hand. It also supplements the first section - public engagement - because therefor knowledge is necessary. Moreover there was a focus on teachers and other education practitioners and how they can use new didactic concepts and teaching methods. (RRI-Plattform-Österreich, 2016)(EuropeanCommission, 2012)
- **Open Science:** The 4^{th} dimension is divided into two parts: Open Science and Open Access. While Open Access is the call to make results, scientific data and infrastructure visible to the public, Open Science goes much further and stands for the accessibility of the whole scientific work flow. That includes research data, working processes, evaluations and publications. The Open Access is reinforced by the Berlin declaration of 2003. Over 600 universities, research institutes and other relevant organizations in Europe signed the declaration. Northern countries like Sweden, Finland, Great Britain try to reorganize their publication system to a complete Open Access policy. (RRI-Plattform-Österreich, 2016)(EuropeanCommission, 2012)
- **Ethics** is based on the fundamental rights and human rights. Beside that it assumes the highest ethical standards for research and innovation. Legal aspects serve as a matter of course and build the foundation for an ethical research. All aspects together provide a more thoughtful

and qualitative research. It helps to guarantee a higher social relevance and greater acceptance. This discourse is rather academic than political. (RRI-Plattform-Österreich, 2016)(EuropeanCommission, 2012)

- **Governance** is more or less the umbrella term for all other key aspects, because it summarizes all of them. There are governance models, which ensure the integration of the other aspects into research. (EuropeanCommission, 2012)

2.3.2. The four P's

Jirotka et al. provided a classification for RRI, using the 'four P's' to categorize different activities. The 'four P's' consist of product, people, process and purpose, while purpose was left aside in most of the articles or only considered shortly. (Eden, Jirotka, and Stahl, 2013)
Jirotkas approach relates directly to the ICT section and it was the base for the ETICA project, which was founded from 2009 to 2011. The goal was to explore issues in the ICT area of emerging technologies by working with the product, people and process dimension. The purpose dimension was skipped for that project. Emerging ICTs are high level socio-technical systems, which have a potential impact on human lives and their environment and an unpredictable development. Emerging in this case means, that these technologies are relevant in a social and economic way in the next 10-15 years. A few examples are affective computing (measure human emotions), artificial intelligence (recreate human or humanoid intelligence with machines), bio electronics (convergence of electronics and biology), robotics or virtual/augmented reality (displaying of artificial objects). (Eden, Jirotka, and Stahl, 2013) (Jirotka et al., 2017)
The following enumeration will consider the product, people, purpose and process dimension:

1. **Product:**
   The product section contains either a physical product or a service, which is relevant for a customer or a user. It serves also as foundation for the other P-sections, which are dependent on that category. The output of the product dimension is usually socially shaped, because it depends, if it is valuable and relevant for the customer. Uncertainties

are rather based on society than on science. The industry and user adaption is able to control the output and development trend. (Jirotka et al., 2017)
In order to review if a product is valuable, ethical concerns have to be considered. Therefor the ETICA project has set its focus and developed four aims, which also serve as a base for the other dimensions. The first step is to *"identify emerging ICTs"* (Stahl, Eden, and Jirotka, 2013, p. 203) which is followed by searching for possible ethical issues of them. The third step is to *evaluate and rank these issues.* (Stahl, Eden, and Jirotka, 2013, p. 203). As a last resort, the output should be suggestions on how to deal with these issues. (Stahl, Eden, and Jirotka, 2013)
In the ICT area the most discussed ethical issues are privacy, security, liability, digital divides and trust. Privacy is about data protection, while payment can be seen as a security issue. Digital divides describe the difference of usage of ICT-tools. The evaluation of emerging ICTs is done in the sections law, ethics, gender and technology assessment. (Stahl, Eden, and Jirotka, 2013)

2. **People:**
The people dimension describes the employees working on a project and their interaction, then again it sets its focus on including researchers, funders and policy makers. These external people help with the composition of research strategies and funding priorities through talks about societal consequences. In comparison to classic RRI it has been extended to public dialog, where regular exchange takes place with the public to get iterative feedback on research. Another method in ICT is reflection among colleagues. (Eden, Jirotka, and Stahl, 2013) (Jirotka et al., 2017)
Furthermore the technology readiness level (TRL) 1-3 is used. The basic level is the formulation of technical concepts and the identification of principles.
As already explained in section 2.2.4 the main challenges with people in ICT are the amount of people working on the same project and if people doing fundamental or applied research have to consider RRI more. (Eden, Jirotka, and Stahl, 2013) (Jirotka et al., 2017)
Moreover there is always the question of how people will use the application, because they can misuse it in a way nobody thought

of, which leads to a huge impact in the end. The consequences also depend on the context of use. (Eden, Jirotka, and Stahl, 2013) (Stahl, Eden, and Jirotka, 2013)

3. **Process:**
The Process dimension covers the organizational structure and operations within a company and the involved persons from outside. In ICT that section is strongly related to influences from outside. The group of involved people is divided into policy makers and industry, researches and civil society organizations. At first policy makers create regulatory frameworks and infrastructure to define a demarcated area for working. Then an ethical impact assessment (EIA) and an ethics observatory will be performed. The EIA is a further development of the risk assessment and defines a coarse structure, while the observatory provides the content for it. The ethics observatory is a shared repository and consists of a collection of methodology, techniques and other concepts, which should be considered. FRRIICT is the first prototype for this technique, which will be covered later in section 2.4.1. Furthermore, there exists a forum for stakeholder involvement. It doesn't only focus on technical aspects, but also on societal impacts. (Stahl, Eden, and Jirotka, 2013)(FRRIICT, 2012)
With industry, researches and civil society organizations the focus is set on reflecting the application usage and technical work. RRI processes need to be kept flexible and dependent on the context or the situation. Too many guidelines would restrict the outcome of the process and the process itself. It is also necessary to pay attention to the socio-economic environment of development and usage at an early stage. (Stahl, Eden, and Jirotka, 2013)
The other part of the process dimension is the organization of a project within a company. In the ICT area, it has one idiosyncrasy: The planning is not done a few months in advance. Planning, developing and the release of a software can happen at almost the same time. That is why there is little time to react and possible consequences can arise much faster. That leads to the need to act more responsive and to have an adaptive management of the innovation process, which involves stakeholders and other interested parties. The responsibility of social needs is shifted to technical innovations and social actors become co-

responsible for the innovation process. (Jirotka et al., 2017)(Schomberg, 2013)(Eden, Jirotka, and Stahl, 2013)

4. **Purpose** refers to the blurring boundaries in the ICT section. It is almost impossible to separate particular software components, because features usually overlap. (Stahl, Eden, and Jirotka, 2013)

Stilgoe et al. provided also a set of sample questions according to the four "P"-categories, which are shown in Figure 2.3 They can be seen as foundation, when starting with RRI. (Stilgoe, Owen, and Macnaghten, 2013)

Lines of questioning on responsible innovation.

Product questions	Process questions	Purpose questions
How will the risks and benefits be distributed?	How should standards be drawn up and applied?	Why are researchers doing it?
What other impacts can we anticipate?	How should risks and benefits be defined and measured?	Are these motivations transparent and in the public interest?
How might these change in the future?	Who is in control?	Who will benefit?
What don't we know about?	Who is taking part?	What are they going to gain?
What might we never know about?	Who will take responsibility if things go wrong?	What are the alternatives?
	How do we know we are right?	

Figure 2.3.: Questions for 3 of the 4 P's(Stilgoe, Owen, and Macnaghten, 2013)

2.3.3. Stilgoe's Definition

Stilgoe et al. introduced in their article a classification of RRI containing four dimensions, namely anticipation, inclusion, reflexivity and responsiveness. Anticipation describes the early valuation of benefits and risks to make considerations wisely, inclusion means the involvement of different stakeholders, reflexivity is reconsidering the values during RRI processes and responsiveness is the ongoing adaption of processes and structures to new insights. (Gurzawska, Mäkinen, and Brey, 2017)

- **Anticipation:** Negative effects of technologies are always difficult to predict and early warnings are hardly possible. Therefore people need to do their best to improve the foresight and increase the resilience. Anticipation consists of the two components prediction and participation: Prediction means to substantiate particular future scenarios and participation tries to open that process. Both processes need to be conducted at the right time - on the one hand early enough, that they are constructive and still can lead to a change and on the other hand late enough, that there is already meaningful information available, where to build on. Furthermore societal outcomes during the process should be examined. Stilgoe et al. work with technology assessments and scenarios, but also with systematic thinking for example or asking "What if...?" questions, to define what is likely, known, possible and plausible. All methods aim at estimating the complexity and the uncertainties of science, shape desirable futures and indicate the direction. (Stilgoe, Owen, and Macnaghten, 2013)(Burget, Bardone, and Pedaste, 2017)

- **Reflexivity** describes methods of self-referential critique. It is referred as mirroring someones own activities or assumptions, which means also the self-monitoring of the whole behaviour. The limits of the own knowledge should be considered as well as awareness of a topic can't always be generalized. Reflexivity can also be a prevention of wrong predictions. (Stilgoe, Owen, and Macnaghten, 2013)(Burget, Bardone, and Pedaste, 2017)
  In general a connection to external value systems, which can be for example a code of conduct, a moratorium or a scientific practice need to be established. The focus is on laboratory reflexivity, where social scientists or philosophers are involved. An enhancement can be the participation of other stakeholders like research funders, regulators or other institutions. Stilgoe et al. suggest, *"not only to reflect their own value systems, but also to help to build the reflexive capacity within the practice of science and innovation."* (Stilgoe, Owen, and Macnaghten, 2013, p. 1571) The boundary between the role responsibility and moral needs to be blurred, which requires openness in innovation processes and the culture of science. (Stilgoe, Owen, and Macnaghten, 2013)

- **Inclusion** describes the technique of bringing in new voices into the innovation process in early stages. In some countries deliberative forums have been organized to include citizens in science. These are a kind of public dialog organized in small groups, where techniques such as citizen juries, consensus conferences or deliberative polling are used. Otherwise with mixed discussion groups - members from science and from the public - interesting outcomes can be achieved.

In participatory activities, the usage of the results and the evaluation criteria requires clarification and transparency beforehand. (Burget, Bardone, and Pedaste, 2017)(Stilgoe, Owen, and Macnaghten, 2013)
Another point are the differences in understanding of the public. Huge knowledge differences can occur, which leads to the fact, that outcomes are not perfect, but they are still good and valuable. Stilgoe referred in his article to Callon's criteria of public inclusion, which are intensity, openness and quality. Inclusion describes the timing of the involvement of different persons and how much the group leader cares about the composition of the group. Openness is somehow similar to the second point of inclusion, because it is about the diversity of the group. Diversity is seen in that sense of who is included in the group and how much control the group has about their spokesperson. Quality refers to the discussions itself, if they are held serious and continuous. (Callon, Lascoumes, and Barthe, 2009) Concrete methods of inclusion are user-driven innovation, participatory innovation and open-source. Open-source is a well known example for the ICT area. (Burget, Bardone, and Pedaste, 2017)
Inclusion is still an ongoing experiment, which leads to a change in governance and innovation. It is an enhancement in that sense, that the public has a say in science, but there are still power unbalances. All in all, inclusion is the strongest dimension, because it also lays the foundation for the other dimensions. (Burget, Bardone, and Pedaste, 2017)(Stilgoe, Owen, and Macnaghten, 2013)

- **Responsiveness** outlines the adaption of processes and the change of directions of response to public values or circumstances, as well as included parties. The main concern is how innovation can be influenced, that it becomes more responsive. In this case, products and purpose are on focus again and the questions mentioned before in Figure 2.3 provide a suitable basis. The grand challenges of our time can be seen as a second thought-provoking impulse for the work. In general, people need to react to new perspectives and knowledge and to adjust their own actions to areas, where more control or knowledge is necessary. (Stilgoe, Owen, and Macnaghten, 2013)
Responsiveness must be facilitated by the company itself, for example the focus on factors such as an open organizational culture, importance

of reflexive learning, encourage creativity, experimentation, focus on public interest, accessibility or transparency. In conclusion it is also necessary to think about possible tensions, technological standards and governance mechanisms, because here is the threat of closing down the innovation process instead of opening it up. Issues can be pressure, different expectations and other dependencies. (Burget, Bardone, and Pedaste, 2017) (Stilgoe, Owen, and Macnaghten, 2013)

Four dimensions of responsible innovation.

Dimension	Indicative techniques and approaches	Factors affecting implementation
Anticipation	Foresight Technology assessment Horizon scanning Scenarios Vision assessment Socio-literary techniques	Engaging with existing imaginaries Participation rather than prediction Plausibility Investment in scenario-building Scientific autonomy and reluctance to anticipate
Reflexivity	Multidisciplinary collaboration and training Embedded social scientists and ethicists in laboratories Ethical technology assessment Codes of conduct Moratoriums	Rethinking moral division of labour Enlarging or redefining role responsibilities Reflexive capacity among scientists and within institutions Connections made between research practice and governance
Inclusion	Consensus conferences Citizens' juries and panels Focus groups Science shops Deliberative mapping Deliberative polling Lay membership of expert bodies User-centred design Open innovation	Questionable legitimacy of deliberative exercises Need for clarity about, purposes of and motivation for dialogue Deliberation on framing assumptions Ability to consider power imbalances Ability to interrogate the social and ethical stakes associated with new science and technology Quality of dialogue as a learning exercise
Responsiveness	Constitution of grand challenges and thematic research programmes Regulation Standards Open access and other mechanisms of transparency Niche management[a] Value-sensitive design Moratoriums Stage-gates[b] Alternative intellectual property regimes	Strategic policies and technology 'roadmaps' Science-policy culture Institutional structure Prevailing policy discourses Institutional cultures Institutional leadership Openness and transparency Intellectual property regimes Technological standards

Figure 2.4.: Six dimensions of responsible innovation(Stilgoe, Owen, and Macnaghten, 2013)

Responsible innovation has the demand to take all four dimensions into account and seek for their embedding in governance. All the dimensions can't be seen as standalone technique, moreover it is essential to draw connections between them. Nonetheless, tensions and conflicts are possible. For example inclusion of the public can be seen as a restriction of the autonomy from a scientists view. In such cases, negotiation of tension causing topics is necessary to prevent conflicts. Figure 2.4 gives an overview about the suggested techniques for each dimension. Several of them have already been described in the actual chapter and the others serve as an inspiration for further reading. Furthermore, certain factors, which affect the implementation are listed below. (Stilgoe, Owen, and Macnaghten, 2013)

2.4. Frameworks of RRI

In the recent years several frameworks for RRI have been developed. Therefor the RRI tools project provides a huge collection of different material and techniques. Beside general explanations about RRI, trainings and a community, the project contains a guide about integrating RRI in practice, self reflection and a tool collection, which is provided as a searchkit. (RRI-Tools, 2015)
The guide gives advice, how to apply RRI in different areas, which are policy makers, research communities, education communities, business and organization and civil society organizations. This guide provides information about the integration of RRI in general, but also gives specific advice for particular areas. That can help with integrating RRI into grant applications or project proposals or defining RRI criteria. In the second part, it refers to the six EU-dimensions and assists with the concrete realization of them. (RRI-Tools, 2015)
The searchkit is a tool to search for different resource types, areas and dimensions. The provided material is either a tool as a resource type, or an inspiring practice, a project or a library element. A tool is a concrete RRI method to apply in a special context. An inspiring practice is a well-proven solution applied in a company. The projects section lists different projects of RRI. Library elements deal usually with special concerns of RRI and provide help for them. (RRI-Tools, 2015)
The self reflection provides different questions for each of the six dimensions to let the users think of the organizations behaviour and strategies in these categories. (RRI-Tools, 2015)

2.4.1. Tools for ICT

Code of Conduct

The ACM Code of Conduct was already depicted in section 2.1.2, but it is also listed as a tool for industry in the RRI toolkit. If companies want to introduce a code of conduct in their company culture, they can use the provided code or see it as a foundation to create their own one. Well-known Codes of Conduct were created by ACM, IEEE and BCS. (Toolkit, 2018)

FRRIICT

FRRIICT is a former ICT framework and it is the abbreviation for "Framework for Responsible Research & Innovation in ICT", which was founded from 2009 to 2011. Its main purpose is to explore ethical issues. The basic approach was to start with a stakeholder analysis and as a second step, relevant rights of them were figured out. Afterwards a work plan was created, how to deal with that issues within the project. Usually a protocol is written, which is shared. Furthermore FRRIICT developed the first prototype of an ethics observatory. (Stahl, Eden, and Jirotka, 2013)(FRRIICT, 2012)

Responsible Innovation Diagnosis in ICT

The Knowledge Acceleration and Responsible Innovation Meta Network (KARIM) provides a diagnosis tool for ICT projects. It consists of questions to the project and reflects it in the manner of where a project stands in the sustainability. Questions are regarding the environment, society, economy and approach of the project. The results are valuations in each section, how sustainable the project has performed. Figure 2.5 shows sample questions, the whole assessment can be done on the website of KARIM. (Gadbois, 2015)

Orbit - Area 4P Framework

Orbit introduced a framework for the practical application of Responsible Research and Innovation. It is called Future AREA Plus Framework, whereby AREA is a shortcut for the contained parts Anticipate, Reflect, Engage and Act. The framework is adaptable to the context and different stakeholders. Figure 2.6 shows the base concept. (Jirotka et al., 2017) (Orbit, 2018)

Approach	- -	-	=	+	++	Comments
Users, clients or beneficiaries were involved in the product or service design (survey, meeting, working group ...). Their expectations and interests were taken into account.	○	○	○	◉	○	
The other stakeholders (employees, civil society, state, financing ...) have been identified and their needs, interests have been taken into account	○	○	◉	○	○	
The project is developed as far as possible in an open and participatory logic (open source, open innovation, crowdsourcing, collaborative innovation, partnership ...)	○	◉	○	○	○	
The basic principles of eco-design (lifecycle, functionality, multicriteria) have been integrated into the product development (ex: green patterns for software, iso14062 standard ...)	◉	○	○	○	○	
The project seeks to take into account the potential transfert of impacts between different sustainability criteria and/or different stages of the life cycle of the product/service (eg. environmental benefit to the detriment of social benefit, positive impact in use but very negative at the end-of-life)	○	◉	○	○	○	
A management system to ensure the quality of the product or service (ISO25000 for software, systems analysis, AGILE method, customers feedback reporting, continuous improvement...) has been set up	○	○	◉	○	○	
Products and suppliers are selected taking into account sustainability criteria included in the specifications (labels as Epeat, Blue Angel, Energy Star, CSR (corporate social responsibility), compliance with the recommendations of the ILO ...)	○	○	○	◉	○	

Figure 2.5.: Example of the diagnosis tool(Gadbois, 2015)

Figure 1. The AREA Plus framework.

	Process Rhythm of ICT	**Product** Logical malleability and interpretive flexibility	**Purpose** Convergence and pervasiveness	**People** Problem of many hands
Anticipate	Is the planned research methodology acceptable?	To what extent are we able to anticipate the final product, future uses, and impacts? Will the product be socially desirable? How sustainable are the outcomes?	Why should we pursue this research?	Have the right stakeholders been included?
Reflect	What mechanisms are used to reflect on process? How might we do it differently?	How do we know what the consequences might be? What might be the potential use? What do we not know? How can we ensure social desirability? How might we do it differently?	Is the research controversial? How might we do it differently?	Who is affected? How might we do it differently?
Engage	How can we engage a wide group of stakeholders?	What are the viewpoints of a wide group of stakeholders?	Is the research agenda acceptable?	Who prioritizes research? For whom is the research being done?
Act	How can your research structure become flexible? What training is required? What infrastructure is required?	What needs to be done to ensure social desirability? What training is required? What infrastructure is required?	How might we ensure the implied future is desirable? What training is required? What infrastructure is required?	Who matters? What training is required? What infrastructure is required?

Figure 2.6.: Area Plus Framework (Jirotka et al., 2017)

As it is shown in Figure 2.6, the framework combines the 4 P's with the AREA concept. In the **Anticipate**-Section, possible consequences are discussed and analysed. **Reflection** means to reflect these impacts, as well as reasons for the research, questions or social transformations. **Engagement** is self-explaining, because it means to open up the former points to broader discussions or public dialogue. The **Act** section puts all deliberations into practice and shapes the direction of research. (EPSRC, 2013)(Orbit, 2018)

2.4.2. General Tools

Most of the existing tools were kept general to provide suitable tools for most application areas. The following section describes a few universal tools, which can be used for the ICT area as well.

RRI Toolcards

The Ecsite European Network of Science Centres and Museums created cards for open RRI conversations. The cards should help to hold a conversation without periods of silence and also provide thought-provoking impulses. They contain statements, questions or tasks to improve the quality of the dialogue. Figure 2.7 shows an example, how the cards look like. The whole set of cards can be found on their website. (ECSITE, 2016)

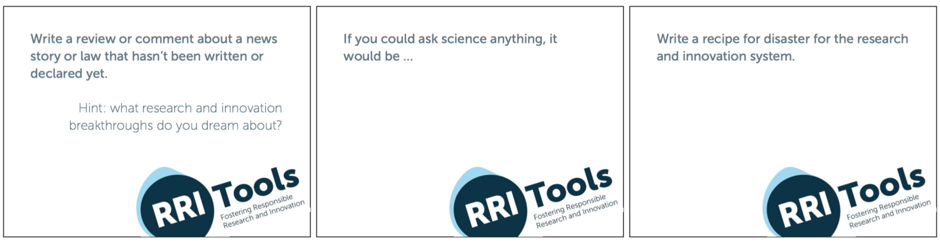

Figure 2.7.: Example of tool cards (ECSITE, 2016)

Paths to Engagement

Paths to Engagement is a flowchart, created as a tool for public engagement. By answering the questions, it helps you what to do and whom to engage and provides ideas on how to engage special groups. Figure 2.8 gives a short insight, but the whole flowchart can be found in the appendix A.1. (SharingScience, 2017)

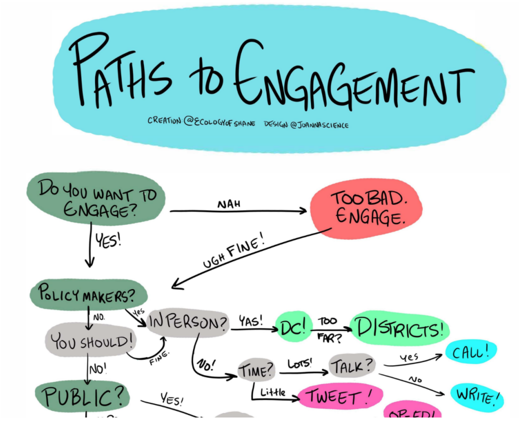

Figure 2.8.: Extract of Paths to Engagement(SharingScience, 2017)

10 Steps of Innovative Dissemination

Innovative dissemination is a quite new tool, which was presented at the LIBER's 47th Annual Conference in Lille in July 2018. It describes the open discourse in research, which fosters a participatory approach that doesn't stick to classic research dissemination. Figure 2.9 shows an extract of the 10 steps, the whole list can be found in the appendix A.1. (Walker, 2018)

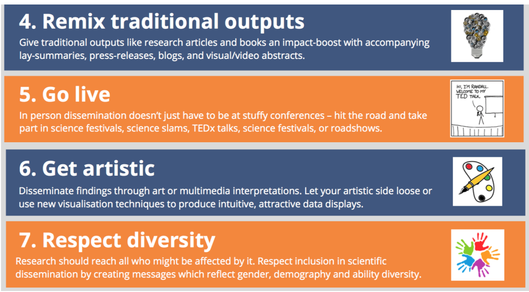

Figure 2.9.: Innovative dissemination(Walker, 2018)

3. Computer Supported Collaborative Work

RRI showed us, how research and innovation can be conducted in a responsible way and how one can deal with possible consequences, whereas the consequences go more in the direction of societal challenges. Computer Supported Collaborative Work searches also for possible impacts, but in that case the research question is, how persons, organizations and the society can be affected by computers. The following chapter gives a short explanation about CSCW, discusses the time-space-matrix and its further development at first and afterwards it reviews the classic techniques of CSCW. The section concludes with a transition to AR and which AR techniques exist in CSCW.

3.1. Definition and Essentials

In the last decades, the amount of communication between people increased. People need to get more information from others, when they work together and that occurs also between different locations of a company. Communication over long distance is needed, which is not physical and face-to-face anymore. That led to a shift in communication and supporting technology. The beginnings were faxes, emails with attachments, blogs, shared file systems and people had to plan stuff without knowing other people personally. Soon afterwards wireless technologies achieved, that communication could be done from everywhere and provided an easier access. (G. M. Olson and J. S. Olson, 2008)
Computer Supported Collaborative Work - also called Computer Supported Cooperative Work - was developed in the 1980s and firstly covered by a

conference in 1989. The European Conference on Computer Supported Cooperative Work (ECSCW) was especially established for that topic. Olsen et. al specified the definition that *"Computer Supported Cooperative Work (CSCW) is the study of how people work together using computer and communication technologies."* (G. M. Olson and J. S. Olson, 2008, p. 498)
Johanson (Johansen, 1988) was involved in the topic from the early stages on and provided the base for the well-known and often used CSCW matrix. In his book "Groupware: Computer Support for Business Teams" he described 17 scenarios of how groupware can be used for users in the then-current situation. Based on that he provided a first attempt for the CSCW matrix, because he was categorizing these scenarios in the form of a table. The classifications were called a little bit different than nowadays, because the time-dimension was divided into synchronous and asynchronous and the other dimension consisted of face-to-face and electronic meetings. (Johansen, 1988) In 1991 he revised his approach and created a graphical representation, which can be seen in Figure 3.1. It splits different activities into a time and place section, whereas time and place can be either the same or different. (Johansen, 1991)

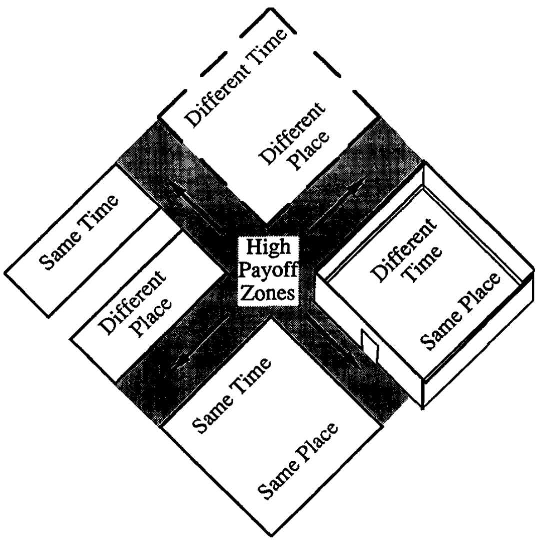

Figure 3.1.: CSCW Matrix(Johansen, 1991)

Figure 3.2 shows the CSCW matrix based on Johansen (Johansen, 1991)(Johansen, 1988), which was expanded by classifying popular techniques. Quadrant 1 has the characteristic of same time and same place. That are face-to-face interactions, which include decision rooms, wall displays, room ware. The section on the top-right corner covers techniques, which are used at the same place but at a different time. That are public displays, team rooms, project management tools. The quadrant in the lower-left corner contains remote interaction, because the place is different, but the time is the same. Video or audio conferencing are the prime examples, but also instant messaging, chats, multi-user editors are widely used. The last section encompasses interaction on a different place and time, for example emails, blogs, websites, group calendars and many more.

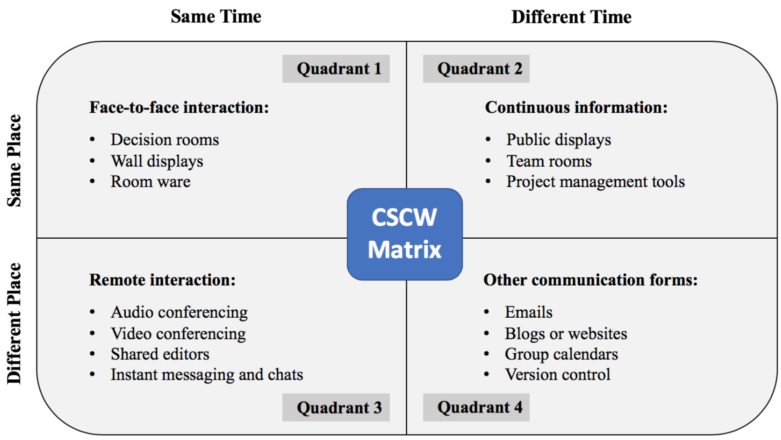

Figure 3.2.: Adapted CSCW Matrix based on Johansen (Johansen, 1991)(Johansen, 1988)

3.2. Classic Techniques in CSCW

In early studies about CSCW audio and video conferences were some of the most researched topics in the area, because they were highly used by people. Such techniques can help to overcome the need of personal meetings, which are time-consuming over longer distances, but they include

also some challenges. In comparison to face-to-face communication, it lacks some features, which are important when talking to people. One problem is trust and commitment. If people have met each other, they are more likely to comply with their agreements. Without knowing somebody personally, people can tend to attribute less importance. A solution to reduce that problem is to chat with unknown people about non-work-related stuff. Still the distance relationship makes things much harder, as for examples characteristics can't be seen properly, so misjudgments can arise. In comparison to personal meetings, audio/video conferences are less social. The amount of informal communication is very low, the focus is on informative talk. Video conferences are still a higher achievement than audio conferences, because audio can be confusing. There arises the difficulty to tell speakers apart or to recognize who is speaking. Also negotiation tasks are simpler with video support. Though video can't be completely equated with personal interaction. Only a limited area of the room is recorded, so participants have no idea, who else is in the room. Furthermore the angle of the camera can influence the appearance of a person. (G. M. Olson and J. S. Olson, 2008)
E-Mail is widely used by people to write messages, which don't need feedback at the same time. But sometimes, the problem is the absence of the feedback or a harsh wording. People tend to write stuff, they won't say personally, for example more offensive, insulting or emotional. (G. M. Olson and J. S. Olson, 2008)

3.3. Current CSCW Trends

Over the time CSCW was refined and more techniques were established. A typical - and in use for a long time - application of CSCW is decision making. Therefore group decision support systems have been developed, which make the process more transparent and structured. Actors can see how the result arises. (Gross and Koch, 2007)
An example for time scheduling for groups is Doodle. The creator can propose several dates and time slots and every participant chooses zero to multiple options, where he/she has time. Doodle suggests that time slot, which has been favored by most of the attendants. Furthermore it is possible to create text surveys with Doodle, for example to ask which location people

would prefer. (Doodle, 2018)
Another well known application are recommender systems for filtering information, because people don't read the whole information, that is available. Recommender systems are well-known for rating music or movies, but there are two types, how recommendations can be generated: item-based and user-based collaborative filtering. For user-based collaborative filtering the user rates for example movies and his/her ratings are compared to other users ratings. The recommendations are created by means of similarity to other users preferences. Item-based collaborative filtering compares a users preferences to rated items and with that similarity, the recommendation is generated. Recommender systems can also be helpful in Requirements Engineering or other systems, where information needs to be filtered. (Gross and Koch, 2007)(Wang, De Vries, and Reinders, 2006)
Beside classical almost organized application areas, CSCW also includes completely distributed software development such as Open Source projects. These projects provide the ability for everyone to collaborate on a project, he/she is interested in. People can help in different areas depending on their knowledge. That can be basic bug reports or helping with documentation or directly contributing to the development of a feature. Open Source Projects work with a version control system, which is visible for all collaborators, so changes are transparent. For coding "Sourceforge" or "Github" are well-known examples. Open Source is not limited to programming related collaboration, an example for another field would be a knowledge database such as Wikipedia. (Purcell, 2014)
Since Johanson (Johansen, 1988) created and defined the CSCW matrix, there was a huge change in technology, so many more technologies need to be included and discussed. In the following, Table 3.1 tries to encompass many new technologies, but because of the high number of existing technologies only a few can be mentioned. Beside that, the borders between the quadrants are blurred and some technologies can't be classified explicitly.

As the borders are blurred for classification of technologies, the following paragraph will focus on these examples.
For instance, pair programming is usually done in an office, where people are sitting next to each other in front of a computer, but it can be done also remotely with screen sharing.

Overview of new technologies in the CSCW-matrix	
Quadrant 1 same time & same place	Pair programming, AR games
Quadrant 2 different time & same place	AR in museums for process data visualization
Quadrant 3 same time & different place	online courses, computer games, AR for maintenance tasks
Quadrant 4 different time & different place	online courses without time slots, decision making tools, Wikipedia, Open Source, Recommender Systems

Table 3.1.: CSCW Matrix of new technologies based on (Johansen, 1988), enhanced with new examples from (Purcell, 2014)(Gross and Koch, 2007)(Bunk-Art, 2016)(Doodle, 2018)(Carvalho et al., 2018)

Computer games are usually played remotely - every user is sitting in front of his/her computer at home and collaborates with other users online. But for example at LAN-parties or in E-Sports Pubs users meet for playing together.
Online Courses are definitely remote, but they can be synchronous or asynchronous, depending on the task.

3.4. CSCW in AR

Augmented Reality appears also as medium for CSCW, as it can be seen in the categorization of Table 3.1. It can improve the collaboration between people, face-to-face and over distance and also synchronous or asynchronous. For almost all quadrants, except the last one, one typical application is listed in Table 3.1. For the first quadrant, augmented reality can help to improve the common workspace. Real objects can be overlaid by virtual ones and people can work on them with gestures to adjust them. For that approach independence is still given for each user. Each user has the control over his/her viewpoint and the displayed data can be different. As the real world is augmented, users can see each other as well. (Billinghurst and Kato, 2002)

For the second quadrant, AR in museums is a good example. People are at the same location and but at a different time. If people can add personal information at special areas of the museum, it supports the collaboration between people. (Bunk-Art, 2016)
For remote collaboration, there are several possibilities to enhance the current technology with AR. In the early years of AR it was used to improve video conferences, because sometimes surroundings are needed as well and not only the face of somebodies interlocutor. In that case AR can show the user in life-size or more users can be displayed at once, which is hard to achieve with a standard screen. Beside that AR can be used for live instructions, where an expert sits at home and sees the workplace and the piece of work augmented, so he can help the person by marking important spots. Remote expert advice can be also used for the medical sector or any maintenance tasks. (Billinghurst and Kato, 2002) (Carvalho et al., 2018)

3.4.1. Collaborative AR Games

As all new projects start small, collaborative AR did it as well. A few projects started with some pilot runs, which were tiny AR games to try out the technical realization of ideas. Billinghurst et al. (Billinghurst, Weghorst, and Furness, 1998) established the idea of "Shared Space", a collaborative open shared workspace with the support of AR. The goal is to assist the user with tools to simplify tasks and that he is still able to interact in the real world with his/her colleagues. The user might not be forced to change his/her working routine. Therefore head-mounted displays are used, that persons can use both hands to interact. The test run was a little game for two players, where objects of different colors needed to be moved to a predefined target. Two roles exist in this game to force collaboration: spotter and picker. The spotter is able to see all objects and can make them visible to the picker by looking at them and saying: "Spot". The picker can pick visible objects by saying "Pick". The object is moved by both players to the target by saying "Drop". The test-run included selecting and moving objects, generating different viewpoints for different users and the use of speech recognition, whereby all techniques can be used for collaborative tasks in real working environments. (Billinghurst, Weghorst, and Furness, 1998)

Wagner et al. (Wagner et al., 2005) preferred AR with hand-held devices to make it more accessible to everybody as head-mounted displays are expensive. Their pilot-run was called the "Invisible Train", a multi-player game for controlling virtual trains on a real toy train railroad track. Users are able to control the speed of their train (two different options) and the track junctions. There were two playing modes: In the first one, people had to avoid collisions. In case of any, the game ends. The other mode is to play competitively, where users have to try to crash into others. The game state of all users was synchronized constantly via wireless network. (Wagner et al., 2005)

3.4.2. Instructions via AR

In industry an important topic is how to share knowledge between employees. With supporting technology that challenge can be simplified. Knowledge is divided into standard procedures and personal knowledge. Standard procedures or basic instructions, which are replicated several times, can be stored in a database. Local and personal knowledge is hard to capture and requires modern technology for sharing. In general the typical industrial setup is, that workers have trainings with segment leaders, when they start at a job. Those segment leaders do practical trainings and show their trainees certain tasks a few times. Afterwards workers have to perform it on their own with being observed from the particular leader. Another method is to read the documentation, but that approach is rather abstract. (Carvalho et al., 2018)
In general trainers have to explain the task again and again, which can be simplified by using AR-technology. Therefore the segment leader can record videos and explanations of certain tasks and mark a special part, where the next step needs to be done. Videos with necessary instructions for the actual step can be superimposed. Installation tasks are shown with head-mounted displays, where the real world is overlaid with instructions and workers can use both hands for the actual work. With that approach people can decide on their own how often they watch the trainings. (Carvalho et al., 2018) That application method can be classified into the 2^{nd} quadrant of the CSCW matrix, because it is used at the same place, but at a different time and by

different trainees.
Another common application is similar to the former one, but an expert is sitting remote and guides the worker through an installation/service/repair task. Both participants also wear head-mounted displays, so that the worker can use both hands for the task and the expert can act location-independent. The expert can see the work environment and can mark parts with annotations to help the user, which is on-site. (Carvalho et al., 2018)
Hoppe et al. extended this approach with the inclusion of Virtual Reality (VR). Therefore the collaboration starts with the worker capturing the object or region of interest and this capture is transformed into a virtual representation. The expert is able to inspect the virtual representation from every perspective and to mark special locations with a laser pointer. Those markings are shown in the augmented world of the worker. Both AR and VR settings are calibrated to retain a stable interface. An anchor point is used for that purpose. Beside the visual representation, the expert can interact with the worker by speech communication. Indeed, Hoppe's case study mentions the disadvantage, that the virtual representation of the object can be imprecise, which impedes the task for the expert. Figure 3.3 shows the original object on the left side and the virtual representation on the right side. As already mentioned before, the expert is able to mark spots with a laser pointer. On the virtual representation the color of the laser pointer is green and on the real object it is red. (Hoppe et al., 2018) Both methods are performed remotely, but synchronous, so they can be assigned to the 3rd quadrant.

3.4.3. Augmented Laboratory

The "Studierstube" (Szalavári et al., 1998) approach is an early concept of augmented laboratory, which combines the real world with an augmented environment. As Augmented Reality is more intuitive than Virtual Reality, it is easier to use for collaboration. The Studierstube system works with head-mounted devices, so people can walk through the room or around an object freely and discover it from different angles. With using the AR technology, people can move in the room without any concerns about obstacles and

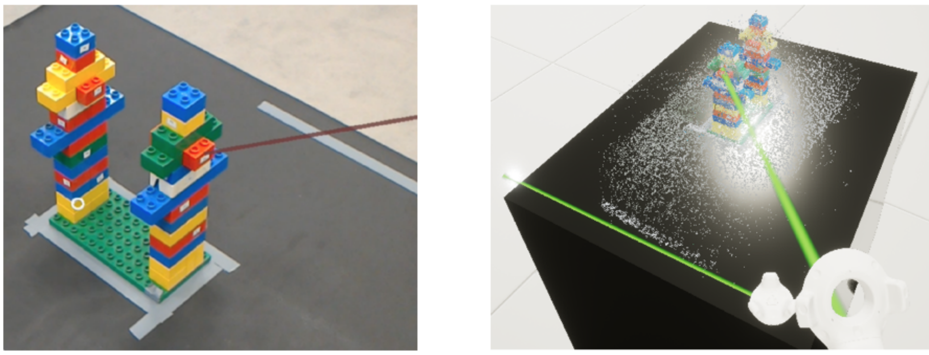

Figure 3.3.: Comparison of real and virtual representation (Hoppe et al., 2018)

communicate with people in their usual environment. The augmented part can be controlled with a Personal Interaction Panel (PIP) by all users. Despite the PIP, a 3D mouse is also available for usage. Furthermore users can configure their viewpoint, so that they can focus on different items and still collaborate with others. Studierstube can be categorized as the 1st quadrant, as it takes place at the same time and location and it improves the face-to-face collaboration. (Szalavári et al., 1998)

3.4.4. Displaying of Medical Data

Watts et al. suggested an AR system, which is able to display the internal anatomy onto a patients body. The system is called ProjectDR and was presented first at the Virtual Reality Software and Technology Symposium in Gothenburg, Sweden in November 2017. Usually medical images such as CT or MRI are displayed in 2D and sometimes even 3D, but the patient is not next to it, which leads to an information loss. AR already tried to overcome that problem with several approaches. Techniques have been suggested with hand-held devices, which is difficult, if the doctor needs both hands and wants to see something closer. Another idea was the usage of head-mounted displays, because it lets the user interact hands-free, but if multiple users want to collaborate, more head-mounted displays (HMD) are needed and

consequently high costs have to be expected. Therefore Watts et al. (Watts, Boulanger, and Kawchuk, 2017) suggest a projected AR system to overcome these challenges. A projector with high illumination and depth-of-field was used for displaying. For tracking, reflective markers are used, which are placed in relative position to each other. These markers help to display the medical images correctly on the patients body and help to cope with shifting of the images because of slight movements of the body such as breathing. Several cameras work together with the markers and at least two markers need to be visible from a certain camera angle. Figure 3.4 shows, how medical data can be projected on someones body. The three light dots are the markers used for tracking. (Watts, Boulanger, and Kawchuk, 2017) (Melnick, 2018)
All in all, ProjectDR seems to be an interesting approach for future medicine. Watt et al. propose to use it on the one hand for medicine students for practical lessons and on the other hand for surgery planning. Both applications would be quadrant 1, because of interaction at the same location and same time.

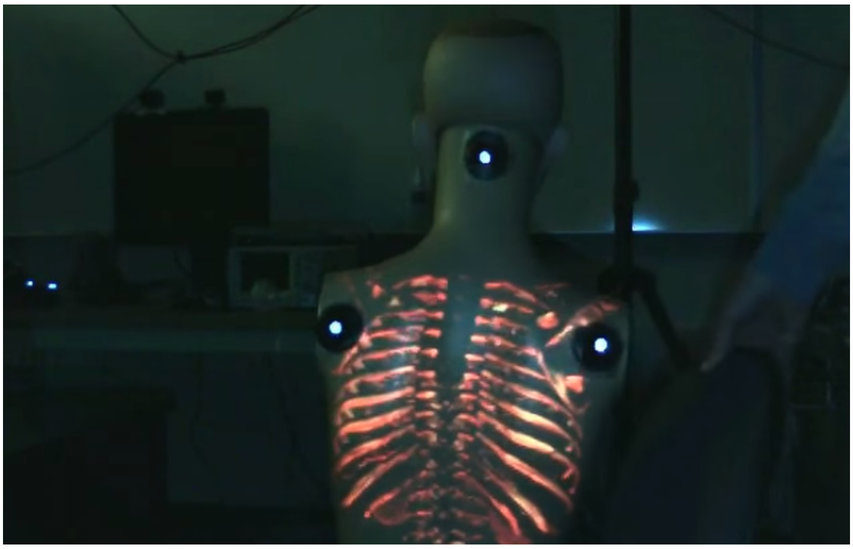

Figure 3.4.: Displaying of medical data (Melnick, 2018)

The system could be extended by letting users mark interesting areas or

anomalies on the projection on an additional layer, which is visible for future users. If that feature is used for teaching, students can repeat the subject matter from the last lesson or look something up, if they forgot some details. If it is used for that purpose, it would be classified as quadrant 3, because the usage is at the same location (e.g. a classroom, practice room in a hospital), but at a different time.
Another application would be directly for the work with patients. If a patient has a complicated injury and needs to go to several doctors with different specializations, the method could be used for collaboration between them. The prerequisite is, that each medical practice has the equipment for this AR technique. Different doctors can mark anomalies on the projection and these markings are visible to other specialists in their own ordination. That collaboration technique can be allocated to quadrant 4, because time and place are different.

4. Augmented Reality

In the former section, CSCW already referred to some collaboration techniques, where Augmented Reality can be a big enhancement. To gain a better understanding of the AR technology, the following section will start with a categorization and explanation of different realities, such as AR, VR and Mixed Reality (MR), before the focus is set to AR. Afterwards necessary terms will be explained, such as marker-based and markerless AR and it provides an overview of existing device types and common AR software development kits (SDK). The subsequent chapter will focus on the difference between multi-user and single-user AR and will establish the connection to CSCW. As the practical part of the thesis will involve manufacturing, as a conclusion typical applications of AR in that area are outlined, but also applications in general to give a broader overview.

4.1. Definition & Essentials

Since Pokemon GO was launched in 2016, the term Augmented Reality gained a higher popularity among people. The general public had an easy access to a new technology and especially young people were using it frequently. It also convinced teenagers, who were usually sitting at home, to walk through the streets, catch different Pokemon characters and interact with others. The complex technology behind this game is AR, which enables for instance a smartphone to overlay the real world with virtual content. (Brewster, 2016)
Before focusing directly on the AR technology, a short classification of different realities is necessary for a proper understanding. Therefor the Virtuality-Reality Continuum provides a good basis. Figure 4.1 shows that continuum established by Milgram and Kishino in 1994. On the left side the

real environment is located, meanwhile on the right side the virtual one. The term real describes direct viewing of objects and scenes. Virtual Reality is a world generated by a computer, it is a completely synthetic world, where nothing is real. The space in between these two opposites belongs to Mixed Reality, which unites the real and virtual world. Therefor two categories exist: Augmented Reality and Augmented Virtuality (AV). AR is based on the real world and just contains overlays of virtual objects. AV is based on a virtual world, but still some real objects are visible. (Milgram and Kishino, 1994) (Lee and Hollerer, 2007)

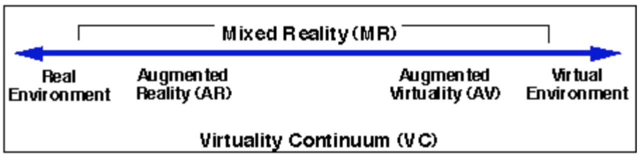

Figure 4.1.: Virtuality-Reality Continuum (Milgram and Kishino, 1994)

In the last years new categorizations and explanations have been established for immersive technologies. The term "Cross" or "Extended" Reality (abbreviated as XR) has been invented. XR is an umbrella term for AR, VR and MR, where the "X" of XR can be seen as variable and can be replaced with other letters to define the particular technology. XR or rather X-Reality is furthermore a registered trademark of Sony, which is a technique for noise suppression. (Northof41, 2018)(Sony, 2018)
Mann et al. (Mann et al., 2018) defines the umbrella term instead as "All-Reality", also written *-Reality, but includes other forms of reality as well such as Mediated Reality, Quantimetric Reality and many more. The following description just includes VR, AR and MR, which is illustrated in Figure 4.2.

- **Virtual Reality** has been already mentioned before and describes a completely virtual world.
- **Augmented Reality** overlays real world objects with virtual ones.
- **Mixed Reality** is placed between Augmented Reality and Augmented Virtuality. In a few references it is described as an extension of Augmented Reality. Real and virtual objects coexist at the same time and the user is able to interact with them. Virtual objects are placed with anchors in the real world. (Quora, 2018)(Mann et al., 2018)

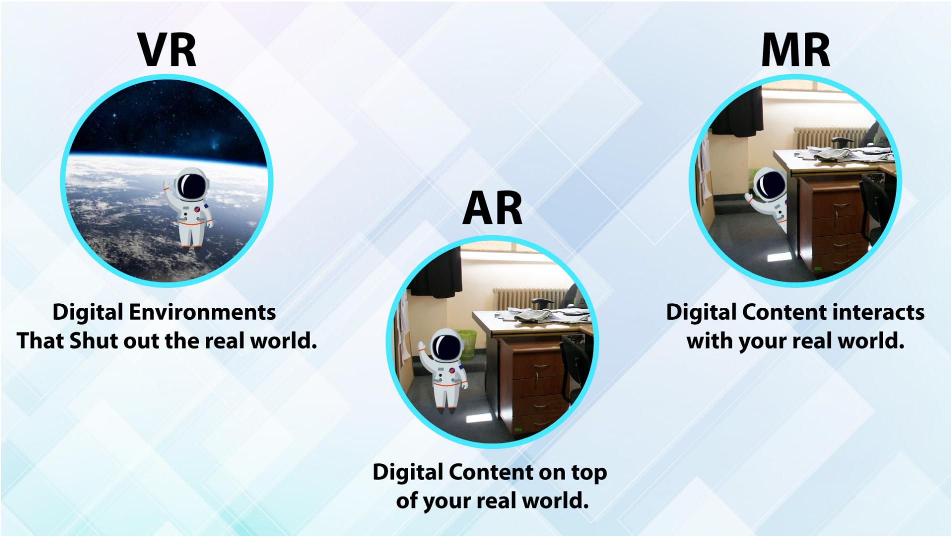

Figure 4.2.: VR-AR-MR (Hajare, 2018)

4.2. Detection Methods for AR

For Augmented Reality several methods and helpers exist to detect the information which is needed that the system knows when to show which additional data. That information can be a marker, an object, a particular shape or GPS-data. Among experts these are called marker-based, location-based, recognition-based or markerless AR, which will be explained in detail in the following sections. (Y.-g. Kim and W.-j. Kim, 2014)

4.2.1. Marker-based AR

Marker-based AR works with special assets, which need to be detected to display information. A marker can be some abstract creation of geometrical shapes with a high contrast similar to a QR-Code, some fancy graphics or even a picture. But for all the different types, it is important, that there are many edges and a high contrast between different shapes. Despite that the shapes in the object have to be in an irregular order, otherwise they won't be easy to distinguish. With such characteristics AR tracking technologies can recognize it faster and the content is displayed more accurate and stable. (Katiyar, Kalra, and Garg, 2015)

4.2.2. Markerless AR

In comparison to marker-based AR, as the name already indicates, markerless AR works without markers. This technique is used for virtual objects, which don't need an anchor and just hover in the screen. Although objects can be placed on a flat surface to increase the realism of the scene. A typical application are furnishing apps, where users can place new furniture virtually in the particular room. For example Ikea already launched an AR app that enables the accurate placement of virtual furniture, that customers have a better imagination of how the new furniture would look like in reality. (Paladini, 2018)(Dasey, 2017)

4.2.3. Location-based AR

Location-based AR describes a technique where different content is displayed accordingly to the position of a user. Usually there are several points of interest, whereby the particular point is found by GPS. As the user is changing his/her position, the information gets updated. A famous example for location-based AR is Pokemon-Go. Different characters and arenas are placed at a spot and the users need to go there to retrieve the information. Another possibility are guidances systems, such as guiding people to the next public transport station. (Y.-g. Kim and W.-j. Kim, 2014) (Brewster, 2016) (Katiyar, Kalra, and Garg, 2015)

4.2.4. Recognition-based AR

Recognition-based AR is a technique for identifying shapes, such as faces, bodies or other items in the real world. After identifying a particular shape, the content overlays the shape. A famous usage for face-recognition-based AR is Snapchat. This app overlays the face with different filters, for example

glasses, a beard or animal ears. It also recognizes the opening of the mouth, so the filters adapt to that movement. (Katiyar, Kalra, and Garg, 2015) (Le, 2018)
Another opportunity is the recognition of real objects through pre-defined 3D models. Vuforia as an AR SDK works with CAD models as a basis, which have to be geometrically non-malleable and to provide a surface with some features. The SDK offers the functionality of a frame around the object, which needs to be scanned. When the object is framed relatively accurate, the scanning starts. (Unity, 2018a)

4.3. Devices

Augmented Reality needs special devices for displaying additional information. Therefor classical devices such as head-mounted or hand-held devices, kiosk systems and projectors can be used, but also newer approaches exist like for example magic mirrors. (AugmentedMinds, 2017)

4.3.1. Head-mounted Devices

Head-mounted devices are special glasses worn on the head. Two different technologies exist for displaying virtual content: video see-through and optical see-through devices. With optical see-through devices users can see the real world through the display and the virtual objects on the display. Video see-through displays record a video of the real world and overlay that with the virtual content. With that approach, the user can't see the real world directly, but the technique is more stable and accurate than the optical see-through variant.(Uchiyama and Marchand, 2012)
The advantage is, that HMDs are a hands-free solution and support gestures for interaction. Furthermore, the user has a bigger viewpoint, which simplifies the design of a lucid layout of virtual objects. But still, HMDs have several disadvantages. Recent studies have shown, that wearing that glasses feels uncomfortable for users. On the one hand the weight of the device itself is part of the problem but also wearing it for a longer time can

cause headache, dizziness or eye troubles. (Friedrich, Jahn, and L. Schmidt, 2002) (Nee et al., 2012) (Krevelen and Poelman, 2010)

4.3.2. Hand-held Devices

A cheaper alternative to HMDs are hand-held devices (HHD), which are for example smartphones or tablets. They provide an easy access to AR, because most of the people own a smartphone or a tablet. The disadvantage is a limited storage and processing capability and a smaller display, but there were several enhancements in the recent years. Further a client-server architecture can help to overcome these processing limitations. (Nee et al., 2012)
Kiosk systems are actually using a tablet as hardware, but the difference is, that it is not used as a movable hand-held device and instead it is mounted to a fixed position. The tablet is working most of the time with the front camera for AR. (AugmentedMinds, 2017)

4.3.3. Projectors

The third classical technique is the usage of projectors, which is also called Spatial Augmented Reality (SAR). Either fixed or portable projectors can be used. The advantages are that users don't need to wear special eye-wear and the possibility to project on big surfaces. As a side effect, portable projectors need to be calibrated to the environment and in general projectors only work indoors because of the light conditions. If users want to overlay non-flat objects, 3D-projectors are needed. (Krevelen and Poelman, 2010) (Nee et al., 2012)
Nike for example is using a projector to color sneakers virtually. Customers have to put a shoe on a special area and afterwards they can choose the color on a tablet. The desired design is overlaying the shoe. (Kiosk-Industry, 2017)

4.3.4. Magic Mirror

Magic mirror is a technology, which revolutionizes the shopping experience. The mirror scans for example the body or the face and afterwards people try out clothes or make-up virtually. When it comes to clothes, people stand in front of the mirror and their virtual representation gets overlaid by the clothes they want to try. They can see how they look from the front. The magic mirror for make-up only scans the face and can project different make-up styles onto somebodies face or show the pores or freckles. The control of these AR apps is typically done by hand gestures. (Sheehan, 2018) (AugmentedMinds, 2017)

To subsume the previous sections there was a big change among displaying technologies. In the last years, some new displaying techniques arose with a high potential to increase the use among general public. They provide an easy access to the people because of usage in the public and the technology has a low threshold to try it out.

4.4. Software Development Kits

In the recent years a big amount of different frameworks for AR appeared and most of them set their focus on different types of AR. The amount of frameworks is too big to cover all of them, but a few famous ones will be described below. We will distinguish between native and multi-platform support.

4.4.1. ARKit

ARKit is the native iOS AR SDK, which is available for iOS 11 and iOS 12. Showing additional content works on the basis of image recognition, but it is also possible to recognize spaces and flat surfaces to place objects.

The second approach was used for the Ikea app. In comparison to other SDKs shared AR-experiences are available for iOS 12 devices. Users can play multiplayer games with different devices and even the current state is saved between multiple sessions. (ARKit, 2018)(ThinkMobiles, 2018)

4.4.2. ARCore

ARCore is an AR SDK developed for newer Android and iOS versions. For the usage of AR apps developed with ARCore, the app ARCore needs to be installed on the phone to provide the necessary functionality. It sets its focus more on markerless AR, therefore it provides features to detect the size or location of surfaces and users can place objects, images or text there. This SDK also offers the persistent positioning of information, that it can be seen by other users. (ARCore, 2018)(ThinkMobiles, 2018)

4.4.3. Vuforia

Vuforia offers AR for multiple platforms, which includes beside hand-held AR for Android, iOS and Windows UWP (Universal Windows Platform) digital eyewear such as HoloLens or Vuzix M300. The SDK is available as build-in plugin for Unity. Primarily Vuforia works with target detection and distinguishes between image targets, VuMarks (mixture between image and QR-Code), cylindric targets, objects and 3D models. Multiple image targets can be tracked simultaneously, which means that several image targets are visible at the same time and each of them is overlaid with another 3D object. Beside that, Vuforia has extended tracking capabilities, whereby the app keeps tracking targets and shows the content for some time, even if the target is not visible anymore. (Amin and Govilkar, 2015) (Vuforia, 2018b) (S. L. Kim et al., 2014)

4.4.4. Wikitude

Wikitude is another well-known AR SDK, which enables cross-platform development for iOS, Android and Windows. It has set its focus on handheld AR. Smart glasses are only supported for enterprise customers. As detection methods image targets and location-based services are possible. The SDK includes hybrid tracking, overlaying with videos and camera zoom. For easy development the Wikitude studio has build-in drag and drop functions for people, who don't want to write their own code. Furthermore it is compatible with famous development platforms such as Unity, Xamarin and Cordova. (Wikitude, 2018)(Amin and Govilkar, 2015)(ThinkMobiles, 2018)

4.5. Multi-User vs. Single-User AR

After having a short overview of the technical background of Augmented Reality, different usage types of AR need to be discussed as well. AR applications can be distinguished by the number of users: single-user and multi-user. Single-user applications are designed for solely working without any interaction with others. Multi-user setups expect the collaboration of users, either directly or indirectly. As the term "collaborative" in CSCW refers to the involvement of more users, multi-user AR belongs to CSCW-systems. Szalavari et al. indicate, that *"most existing augmented applications are single-user setups, or do not exploit the multi-user character of their systems."* (Szalavári et al., 1998, p. 39) Since that study, AR has achieved big enhancements and many multi-user AR applications have been created.
Some applications can be explicitly assigned to multi-user AR, such as AR-supported maintenance tasks (Carvalho et al., 2018), where a worker is wearing a head-mounted display and the expert is coordinating the task remotely and can place markings. In the extended version of Hoppe (Hoppe et al., 2018) the expert sees a virtual representation of the object. Also the "Studierstube" approach (Szalavári et al., 1998) belongs to that category, because people can interact together at 3D objects. Billinghursts "Shared Space" (Billinghurst, Weghorst, and Furness, 1998) also allows the interaction of more users with head-mounted displays. People interact with each

other through gestures in an augmented area. Wagner et al. created a collaboration technique with hand-held devices (Wagner et al., 2005) to make AR more accessible to everyone. Both projects carried out some experiments and case studies with users, presenting their technology with tiny games.
Beside that, a huge amount of technologies exist, which were primarily created for single users. There is actually no direct collaboration task given through the support of AR. But still, people can use these technologies to collaborate or they have the potential to be extended for collaboration. A common example is the usage of AR to plan the furniture of a new flat. (Khairnar et al., 2015) Objects can be moved in a room to try out, how it will look later. People can use it on the one hand alone and on the other hand together with the reseller or some family members to visualize and discuss the planned furnishing. Such systems can be extended for collaboration insofar, that people can place and move objects in the room with different phones or that the state is saved between sessions.
Already a few apps for furniture planning exist, which are supported by hand-held devices to make it accessible to everyone with a smartphone. People, who want to order furniture in the Internet, benefit from such apps, because they can have a better impression, how it will look in reality in the room in comparison to if they haven't even seen a 3D representation of the desired item at all and only can refer to pictures. Also IKEA launched an AR app for furniture, where customers can use 3D models of the furniture items and place or move them in their flat. (Xue, 2017)
A complete single-user application was for example created by the Bunk Art Museum in Tirana, as they included hand-held AR in their exhibition. The exhibition is about the dictatorship of Albania and its impact on the society. People can scan different images with their smartphone and then the person is moving his/her mouth on the screen and telling either stories of a person or more general information, which matches the exhibition space. (Bunk-Art, 2016) This system could be extended to a multi-user setup that enables people to place own information and experiences at different parts of the exhibition, which is then visible for all future visitors.

4.6. Applications in Manufacturing

Since the case study in a later part of this thesis will be about AR in the manufacturing and engineering area, the following chapter will give an overview about existing AR applications in manufacturing.
Due to the high dynamics and fast pace of innovation cycles, a flexible strategy for information transfer between employees is needed. Augmented Reality can help to achieve this goal and improve the collaboration between employees. (Fruend and Matysczok, 2002)

4.6.1. Plant Planning

AR can be used to visualize the inner structure of a factory. The prerequisite is to have 3D models of different machines and other components needed in the plant. Users can position virtual objects somewhere in the room to try out how they can be located that it is suitable for the employees. Furthermore the power supply for electricity or water connections can be considered as well. That technique allows collaborative working, if the positioning state is synchronized between devices or users work together at one device. (Fruend and Matysczok, 2002)

4.6.2. Maintenance and Assembly Tasks

Maintenance and assembly tasks supported by AR are a quite common application area in manufacturing. Users wear a HMD for the service task, so they can use both hands for working. With the help of AR additional information for the task is displayed. One method is to display instructions or tutorials, which are fetched from a database based on several problem descriptions. The other mode is a connection to an engineer - which is called expert support - who can see the viewpoint of the worker and help with analyzing the problem remotely. As already mentioned in section 4.5, the expert can place markings on important components. (Friedrich, Jahn, and L. Schmidt, 2002) (Nee et al., 2012)(Krevelen and Poelman, 2010)

4.6.3. Logistics

Logistics can be supported by AR for warehouse picking tasks. Workers have to wear a HMD or use a hand-held device and navigational aid for picking up objects is provided by AR. Arrows can show the directions on the floor. Furthermore the required object gets highlighted. Weight checking systems are sometimes included to prevent errors. (Büttner et al., 2017)

4.6.4. Quality Assurance Tasks

AR in Quality Assurance (QA) is quite similar to AR for maintenance tasks, because it provides instructions, which tasks have to be performed. If the particular tools have QR-Codes, AR can examine, if the correct tool was picked. The other possibility is the superimposition with images, which can be compared to the actual status.
Crash Tests also belong to the QA category - the base functionality is the superimposition of calculated crash results. The crashed car is overlaid with the calculated result to provide an immediate comparison to see potential differences. (Friedrich, Jahn, and L. Schmidt, 2002) (Wright, 2017)

4.6.5. Product Design

In car industry, AR was also used for product design, especially for interior design. Therefor the interior is overlaid with another design to try out different fittings.
Another sub application area is interactive design, where participants are able to change colors, shapes and other characteristics of real and virtual objects. That allows even the creation of new designs through different modifications. (Nee et al., 2012)

5. Case Study

The first part of this thesis provided theoretical insights to RRI, CSCW and AR to serve as a basis for the practical usage. In the second part the different concepts will be implemented and discussed. The chapter is split up into four sections: the use case definition, the technical realization, implementation details and practical outcomes. At first, a description and an analysis of the use case are provided, followed by establishing the link to RRI concepts and the classification of CSCW.
The second part contains the whole process of the technical realization. The short overview about AR of the former part will be extended, when more details are necessary for the practical implementation. It starts with the selection of the framework, the device and platform, which is followed by control mechanisms are discussed, followed by the runtime import, especially data types and repositories.
Afterwards a few implementation details are explained, such as Unity-related features, API calls and processing of 3D models. The chapter concludes with practical tests and outcomes.

5.1. The Use Case

For manufacturing, AR applications gained a higher popularity in the recent years. Many researchers tried to find new fields of application for these technologies and carried out lots of practical tests and research to improve the actual development. In section 4.6 several existing applications have been analyzed to outline the state of the art in AR. As one can see, a couple of applications already exist in that context. For the one thing that leads to a higher difficulty to find a new field of application, then again it is necessary to analyze the worthiness of the idea for AR.

Pokemon Go contributed to a wider availability of AR and that popularity triggered a higher amount of ideas. People and companies tried to integrate AR in various sections in the daily life and work life. With that enthusiasm, people forgot to analyze their ideas to have a realistic evaluation, when showing additional information is an enhancement with AR and when it can be also shown in 2D mode. It is important to review, if the idea is really worthy to do it with AR or if it just looks fancy, but actually the user experience would be better in 2D mode.
The continuous section starts with the definition of the use case, expanded with a story board for a visual representation and the value proposition canvas, followed by a short explanation of the former use case, which is necessary to explain the selection process with the help of RRI concerns. Afterwards all criteria of CSCW are discussed for the use case to check how it can be classified.

5.1.1. Requirements from the Workshop

The Institute for Production Engineering(in German: Institut für Fertigungstechnik, abbreviated as IFT) has set its focus on mechanical engineering and therefor two workshops with several machines exist at the university campus. One of them is used as an exercise workshop for students, who haven't used milling or drilling machines before, the other one has professional employees for producing different components.
In the production of different components problems can occur as for instance unintended collisions, which can even result in tool breakage. Such incidents can lead to higher costs because the particular tool has to be replaced and the employee has to repeat the task. The aim is to avoid or at least decrease such incidents by improving the workflow.
In production different tools and clamping elements can be used and as a result, the working space can't be fully used. Especially for older machines the workspace and the tools are not available as 3D models. Employees can only estimate based on their experience, if a component fits into the machine. Furthermore, the kinematic of a machine can't reach all spots on a component, because the rotation angles and the axle restrictions vary

between different machines.
According to all that difficulties, it would be an enhancement to test it before the real component is processed in the machine. For some machines, simulation programs exist either directly at the control panel of the machine or the other possibility are computer programs for simulation. For the second case, the difficulty is the poor availability of computers in a workshop.
That leads to the necessity to take other possibilities into consideration. The idea is to visualize the component directly in the working space of a machine with the help of AR. This intervention takes place at preparation time and the component will be processed virtually beforehand. The program will be executed using the virtual representation and the employee is able to control visually, if a collision would occur.
Figure 5.1 shows the milling machine, which was used for testing the AR app. The model of this machine is called Emco VMC 600 and it is equipped with a Heidenhain control. The type is a 3 axes milling machine.

Figure 5.1.: 3-axes Milling Machine

5.1.2. The ICT-related Aspects of the Use Case

After an analysis of the use case from the perspective of Production Engineering, also ICT-related prerequisites and standards need to be included. The following section will encompass requirements for the detection method, positioning of 3D models, runtime import and a tutorial section.

Detection method

For AR, the most important thing is, that a special detection method is needed that the application knows where to show the virtual content. That can be a marker, an object, or a ground plane. For that use case, ground plane detection wouldn't work, because a horizontal, completely flat surface is required and that doesn't exist in the machine. Object detection is more complicated, because a 3D model of the object is required and the detection is based on a high contrast of colours of the object. The clamping device is single-coloured, so good detection and tracking are not guaranteed. A marker is usually an image, which is placed exactly at that location, where the virtual content should be shown. That method is the most suitable for the machine, so it was selected for the AR app.
For image targets, further requirements arise from the machine itself. First of all, the markers have to be placed in a wet and filthy environment, so the image target has to be water-resistant. The second issue is that fixed markers aren't possible, because depending on the component different clamping devices are mounted. The third requirement is, that clamping devices have a particular size, so the size of image targets is also limited, they shouldn't exceed a width of 12cm. On that basis the AR SDK needs to support all these requirements for detecting image targets.

Positioning of the 3D model

When an image target is placed in the machine, it doesn't mean, that the virtual component is shown exactly how a worker would put the raw material into the machine. That calls for an additional control of the virtual component. For one thing, the user should be able to move the component along all three axes, then again rotation along the axes should be possible. If the desired position and rotation is achieved, the model should stay stable in relation to the target.

Runtime Import

The visualization of components is especially interesting for individual parts. For serial production more knowledge is available, so it would be an exception, that such a problem will occur. For individual production, for each component a different 3D model is necessary. Updating the app for every new 3D model would be cumbersome. To have a fast access to new 3D models, an import of 3D models at runtime is the most user-friendly solution.

Tutorial

However, not all employees can be expected to be aware of the usage of AR. Therefor the application includes a short tutorial about how image targets can be placed in the real world and how they can be scanned and moved with the smartphone to adjust the position and rotation.

5.1.3. Storyboard of the Application

The former section described the use case and the technical requirements on which it is based. In order to have a better overview of the AR app and its usage, a storyboard will illustrate the use case. Figure 5.2 shows the

storyboard, which is composed of four cells.
The first image shows the start screen of the application, where the user can select between the following categories: start AR, model selection and a tutorial. The second image shows the 3D model selection.
The third picture switches to the machine itself and shows that the marker needs to be placed inside the milling machine at a particular spot. The story board finishes with an outlook, how AR will look directly in the machine. Here several buttons are needed to position the 3D model correctly in the machine. They regulate the shift along the x, y and z axes and the rotation around all axes. With a plus and a minus button the distance can be controlled, the x-button switches to y and z when clicked. The other two buttons distinguish between rotation and movement of the 3D model.

5.1.4. Value Proposition Canvas

The value proposition canvas is an assistant tool for business model innovation and service design. Most of the time people think only about the functions of a product and not about the actual profit for a customer, possible side effects or that it fits completely to the customers' needs. Therefor the value proposition canvas analyzes such issues to create a better customer experience. Figure 5.3 shows the canvas for the selected use case.
The right side of the canvas describes the jobs of the customer and includes pains and gains. The pains describe possible hurdles for customers and the gains include their desires and expectations. For that use case, the customer job is in the field of Production Engineering. The worker has to process a component correctly without any collisions, because such incidents can lead to tool breakage. Therefor the worker has to estimate, if a component fits into the machine and the cutter doesn't collide with anything. Pains for this job occur especially for newer employees, which don't have much experience. Especially if they are insecure about their own skills, they have to call an experienced worker to help them with the estimation. Gains are for example, that possible collisions can be verified in a fast and easy way, without relying on the own estimation skills.
The left side of the canvas consists of the value map for a particular product or service, gain creators and pain relievers. The last two relate to the cus-

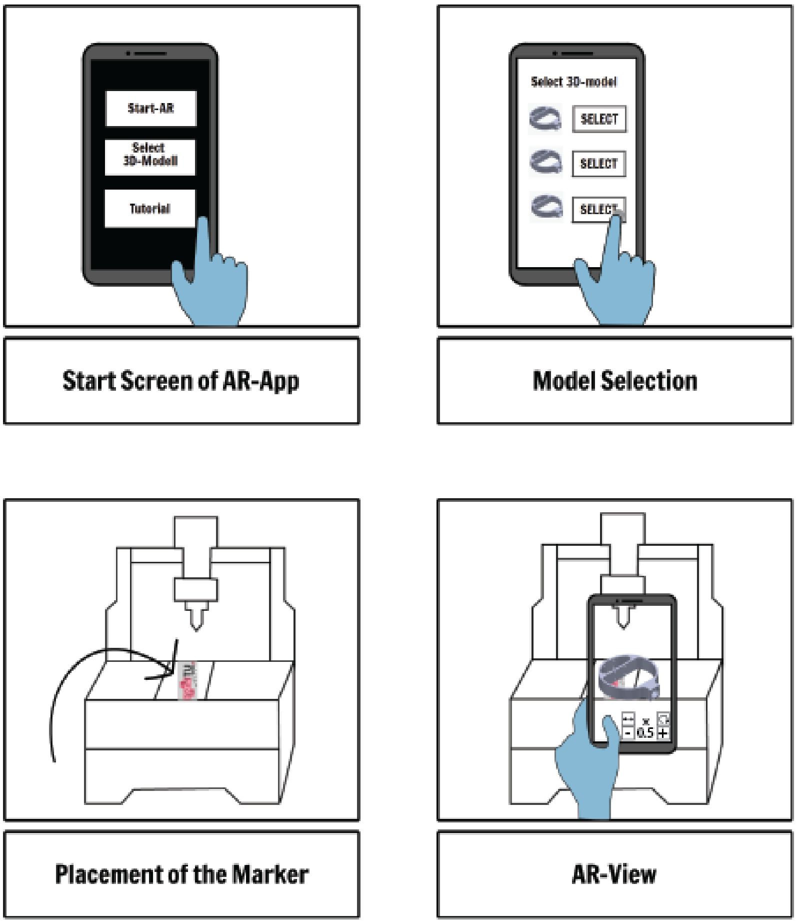

Figure 5.2.: Storyboard of AR application, created with https://www.storyboardthat.com/

tomer section, because they help to achieve the gains of a customer and to reduce the pains. The product is an AR app which helps with the collision detection for the component to be processed. Gain creators are for instance the testing of possible collisions with a smartphone application. A virtual 3D model of a component is loaded into the work space and the processing program can be executed on the virtual component. Furthermore 3D models can be exchanged at runtime. Pain relievers are that inexperienced workers can verify a possible collision with an app and don't need any help of another person. Despite that, the tool can improve their estimation skills by seeing the processing virtually. All in all the most important issue is the reduction of the tool breakage. (Osterwalder et al., 2014)

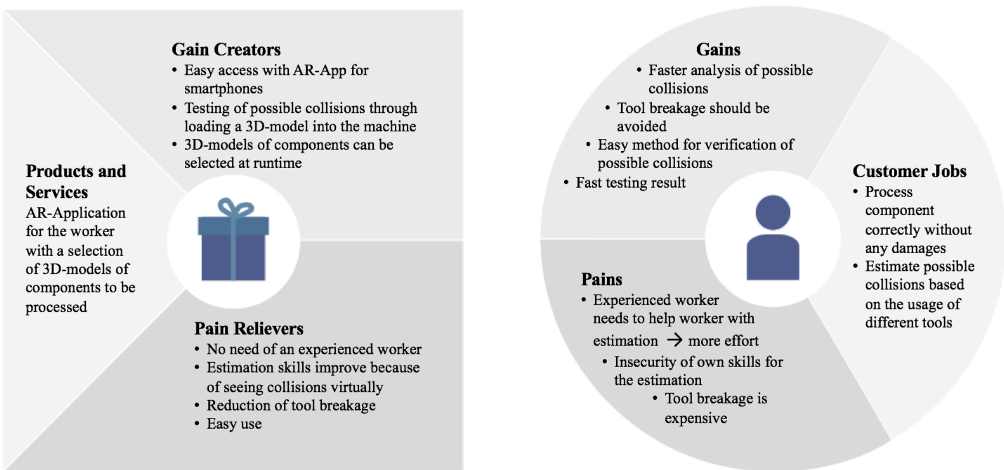

Figure 5.3.: Value Proposition Canvas for Collision Detection AR Application based on (Osterwalder et al., 2014)

5.1.5. The former Use Case

Before the use case described above was found, another use case was discussed. It will be explained below shortly to provide a basis for the comparison of RRI aspects for both use cases.
The first idea, of how AR can be used for manufacturing was to display

machine and order data with AR. The aim was to scan the machine and overlay it with the particular information, for instance:

- Is the machine running at the moment?
- Number of pieces per day
- Remaining time of the actual component
- Remaining time of all pieces
- Completed orders
- Follow-up orders
- In case of more machines: overview of actual orders on each machine
- Calculation, if all pieces are ready until the delivery date
- Highlighting of delayed orders

That use case is suitable for serial production, where multiple components of the same type have to be produced.

5.1.6. Relation to RRI

RRI was the first theoretical concept in this thesis, presented in chapter 2. As the name RRI indicates, the main focus is on the term "responsible". Therefore different classifications have been provided and the relation to RRI of the actual use case will be established with the categorization of Stilgoe et. al, described in section 2.3.3.
Additionally, both use case ideas will be compared by covering typical concerns of RRI in ICT area. That are mainly privacy issues, but also security issues will be raised.

Reference to Stilgoes Classification

Stilgoes classification contains the sections anticipation, reflexivity, inclusion and responsiveness for RRI. With the selected use case the focus was set primarily on inclusion and responsiveness, because the outcome - an AR app for collision detection - relates to the workshop of the IFT, so their opinions had to be considered to create a valuable product.
The **inclusion** process was carried out with several visits in the workshop

and discussing small parts of the AR app. It started with a short presentation of the AR technology, that everybody has the same level of knowledge and an imagination, how the result can look like. The talks continued about which control elements are necessary to position the virtual model and which detection method would be possible. Furthermore the usage of virtual buttons and UI-buttons has been reviewed. Then tests have been carried out, how to place image targets in the machine and verify their stability. Concerning this matter the outcome was, that water-resistant image targets are necessary and that VuMarks are more stable than image targets in that manner, that parts of the target can be overlaid by the cutter and the virtual object remains stable.
Responsiveness was conducted by reacting directly to the feedback after discussion groups in the workshop. The outcome was the implementation of positioning the virtual model along the x, y and z axes and the rotation around all three axes in 90 degree steps and a slider for an accurate rotation. The decision for the buttons was the usage of UI-buttons, because they can be smaller and are easier to click. For the stability, the detection method has been changed from image targets to VuMarks, but that will be explained in detail in section 5.2.3.
Anticipation is hard to examine with this use case, because the application area is limited to manufacturing and negative consequences are always hard to predict. A very common negative side effect of technologies, which support people at certain tasks, is that people tend to rely too much on the supportive technology and don't want to think for themselves and use the technology more frequent than necessary. They rely completely on the technology and forget that technologies can fail for several reasons as well. That also can happen with that use case, but the worst consequence is tool breakage, which also could happen without using an AR app for collision detection.
Reflexivity focuses more on self-reflection and self-mirroring of somebodies own activities. For that use case reflexivity was carried out during the development process of the AR app. The app has been tested several times and verified for meaningfulness and usability. The aim was to produce a reasonable and pleasant to use AR app.

Privacy and Security Concerns

The first idea for an use case was displaying different data of a machine with AR. As already described in section 5.1.5, the data include the remaining time for components or production series, quantities per day, follow up orders and calculations of possible delays. If somebody is reading that list for the first time, the items just seem to be some machine data, which don't have anything to do with a person. Though that is not the case. Most of the data have a direct relation to the performance of a worker and depend on his/her way of working, but also external influences.
Remaining times for production series are based on the time needed for former components and relate to the speed of the worker, same as the calculation of delays or the quantity per day. People, who look at this data might just see numbers, but no explanation why a special number is divergent. If at one machine, the number of produced components per day is lower as usual, it could lead to the prejudice, that the worker might be unmotivated or slow. With that data it is possible to monitor the workers. That infringes the privacy of people, because a really precise monitoring of the performance is possible.
The chosen use case focusing on collision detection doesn't have the problem with such privacy and monitoring issues, because showing 3D models of components doesn't infringe somebodies privacy. Though the runtime-import of 3D models has to be discussed, as a Google API is used. The Google API lets a user upload 3D models and lets him choose, if they are private or public. The 3D models needed for the use-case have to be private, because unauthorized persons shouldn't see the virtual components of the workshop.
The aim is to let a user call the API in the AR app and retrieve the uploaded 3D models. For public models, an API key is needed to have access, whereas for private models OAuth2.0 - a protocol for authorization - is necessary to fetch them. The possibility to mark 3D models as private solves the privacy issue. With OAuth2.0 the security issue can be handled, that only authorized persons have access to certain data.

5.1.7. Relation to CSCW

Computer Supported Collaborative Working was the topic to be discussed in section 3. As a short recap, it describes, how people are affected by technology in their daily work. That was categorized into same or different time and same or different place, as shown in Figure 3.2. Hereafter the use case will be analyzed, how it can be categorized.
The use case involves the testing of virtual representations of components in milling machines, if a collision could occur at a real component. That is usually done by one person, given that point of view, it would be categorized as **single-user** application. But if the processes in the background are considered as well and that people can do the collision testing together for learning purposes, the application is definitely a **multi-user** application.
In section 3.4 a few applications of AR in manufacturing have been discussed, where AR for training purposes has been mentioned. The collision detection app can be used for training purposes as well, although it is not the primary field of application. For instance it can be applied for the education of apprentices or new employees. If somebody is new at a particular machine or even in the job, it is hard to estimate the distances and if a component will fit. Workers with a considerate experience can estimate it quite accurate, but for newcomers it is really difficult. Therefor the trainer of apprentices can use the AR app to show them, how a particular component is processed virtually. If apprentices see it a few times even for ordinary components, they probably learn faster to imagine the handling process and the distances. That usage can be categorized to the first quadrant of CSCW - **same time and same place**.
For the collision detection app a few steps have to be handled in the background. New 3D models of components don't get uploaded by itself to the AR app, somebody needs to prepare them and upload them to a specific location, where they can be accessed by the app. That is done before the component is needed and usually not in the workshop, but rather in the office of the department. That preparation tasks are done at a **different time and a different place**, so they belong to the 4^{th} quadrant.

5.2. Technical Realization

The former chapter described the use case itself, including information about the structure of how the app will look like and established a relation to the theoretical concepts of RRI and CSCW.
The subsequent section will focus on the technical realization of the use case. Therefor it will start with the framework and device selection, continue with detection and control methods, before focusing on data types for 3D models and repositories for model selection.

5.2.1. SDK Selection

In section 4.4 a few SDKs have been described for the framework selection. Each of them is a pioneer in a special area and has its advantages, but they contain also technical restrictions, which can impede the development of a specific AR app. For the use case described before, the following requirements are necessary:

- A particular spot in the machine - usually at the clamping device - must be detected. Since the recognition of objects - also called models - is not fully sophisticated and proved, image targets can be used as an alternative for recognition. Therefor we have to overcome a few challenges. First the clamping device can change depending on the components to be produced, so it is impossible to place a fixed marker there. Second, the clamping devices have different sizes and some of them are relatively small, so the marker should not be larger than 12*15cm.
- **Runtime import:** Using an AR app to test possible collisions before the real production is useful especially for individual orders, so the 3D model to be tested in the machine will be changed frequently. Due to the usage of new models all the time, they can't be hard-coded in the application, otherwise the app would need a deployment for each new 3D model. Therefor 3D models need to be exchanged at runtime. That problem seems to be quite new for AR, so only a few resources exist for this purpose. One of them is Google Poly, which contains a huge

Comparison of SDKs for Augmented Reality				
	ArKit	ARCore	Vuforia	Wikitude
Image targets < 12*15cm	✓		✓	✓
Google Poly support	✓	✓	✓	
Positioning	✓	✓	✓	✓
Android devices		✓	✓	✓

Table 5.1.: Comparison of AR-SDKs

database for 3D models and allows also the upload of own models. Furthermore it provides an API for several development platforms.
- **Positioning:** The 3D model can be moved with buttons, the positioning along all three axes including the rotation around them should be possible.
- **Devices:** For an easier access, the application will be developed for hand-held devices, more specifically, Android phones.

Table 5.1 provides an overview, if the particular framework supports the desired properties. **ArKit** includes image targets, Google Poly support and positioning, but unfortunately only iOS development is possible. (ARKit, 2018)

ArCore also scores well in the listing, but the detection possibilities are insufficient for the use case. It actually supports image targets, but they need to have a minimum size of 15*15cm, so it would be too big for some clamping devices. The other method is ground plane detection, for which a flat surface with a certain size is needed (Practical tests have shown, that the surface needs a minimum size of approximately 1/4 m^2) and the surface needs to be horizontal. Projections on walls are not possible, as vertical surfaces are not supported. (ARCore, 2018)

The **Wikitude** fulfills the requirements according to the detection method, positioning and device support, but the support for the desired API (Google Poly) was not given. (Wikitude, 2018)

Vuforia fulfills all the requirements that are needed for the given use case. It doesn't define a minimum size for image targets, but suggests an ideal size of 5 inch (12.5cm) for reliable tracking. The SDK even provides Vu-

Marks, a mixture of image and QR code. Therefor a minimum size of 1 inch (2.5cm) is required. Furthermore different 3D model data types are allowed and Google Poly has created an API for Unity, where the Vuforia SDK is integrated. (Vuforia, 2018b)

Vuforia with Unity as development environment fulfills all these requirements, so that SDK was chosen for the implementation of the use case.

5.2.2. Device and Platform Selection

Different devices, which can be used for Augmented Reality have been explained in section 4.3. The main devices were head-mounted displays, such as AR glasses, hand-held devices like smartphones or tablets and projectors.
Projectors are not suitable for the use case, because they are projecting to a fixed spot. Depending on the milling machine, either the clamping device is moving along the x and y axes or the cutter is moving along all three axes. For the second scenario a projector would work, but it would be a high effort, because the projector needs to be calibrated to the environment for each usage, if it is portable, or otherwise a fixed projector would be an obstacle for the people who walk by.
Head-mounted devices would be a nice feature for the use case, but they are actually not needed. The advantage is that the field of view is bigger in comparison to a HHD, but for that application a smartphone provides enough functionality. Beside that, the access to smartphones is easier than to HMDs. Usually just a few companies own HMDs and moreover, they need to be calibrated to each user, which impedes the usage. On the contrary, almost every person owns a smartphone and an app is easy to install. For that purpose, smartphones were chosen as the output device.
The selected target platform of smartphones is Android, because the creation of packaged apps is simpler. iOS requires a paid developer account for building and publishing apps. Building with a free provisioning profile is only possible for testing purposes, which means, that the app is valid for a short period of several days. (Apple, 2018)

5.2.3. Detection Method

The detection of markers was already elucidated before shortly in section 5.1.2, but this passage will focus on the comparison of image targets and VuMarks.
Vuforia provides its own target manager, where users can check, if an image is suitable for AR and are able to create their own VuMarks. Suitable means, that there are enough features at the image, which can be detected. Features are edges and corners with a high contrast to the neighborhood.
For testing purposes, an image target was mostly used in the beginning. Regarding to Vuforias target manager, the image target was quite good. It had a 4/5 star rating, which seemed to be satisfying in the first tests. Figure 5.4 shows the original image on the left side and the visualization of the features on the right side. Each feature is marked with a yellow plus.
After carrying out further tests directly at the machine, the results became unsatisfactory. With a certain distance or if the image target was covered partly from above - which happens easily with a drill bit or cutter - the 3D object started flickering and sometimes it even disappeared. That happened even more often, if the object was not displayed directly on the target and instead shown either left or right next to it. Using such an unstable detection method was not possible for the use case, because accuracy is demanded.
The other attempt was the usage of VuMarks, a mixture of QR-Code and image, which was invented by Vuforia. The tests with VuMarks were much more satisfactory, because the 3D object remained stable, even if half of the VuMark was covered and the object was next to it. That was the reason, why VuMarks have been selected as detection method for the AR app.

Figure 5.5 shows the creation process of a VuMark in the Adobe Illustrator. The left side shows the verification tool, which checks if all elements have been created correctly. The picture on the right side shows the VuMark, which was already marked during the verification process. The VuMark setup starts with the definition of encoding, if it is either a string, a number or bytes and the length. Depending on the length a special amount of elements is required. After that, the clear space has to be created, which is the light gray rectangle in the background. The contour is the red symbol of the Technical University (TU), outlined by a black border. Both are not allowed to be bigger than the clear space. The contrast between the border

Figure 5.4.: Image Target including a visualization of the features (Vuforia, 2018a)

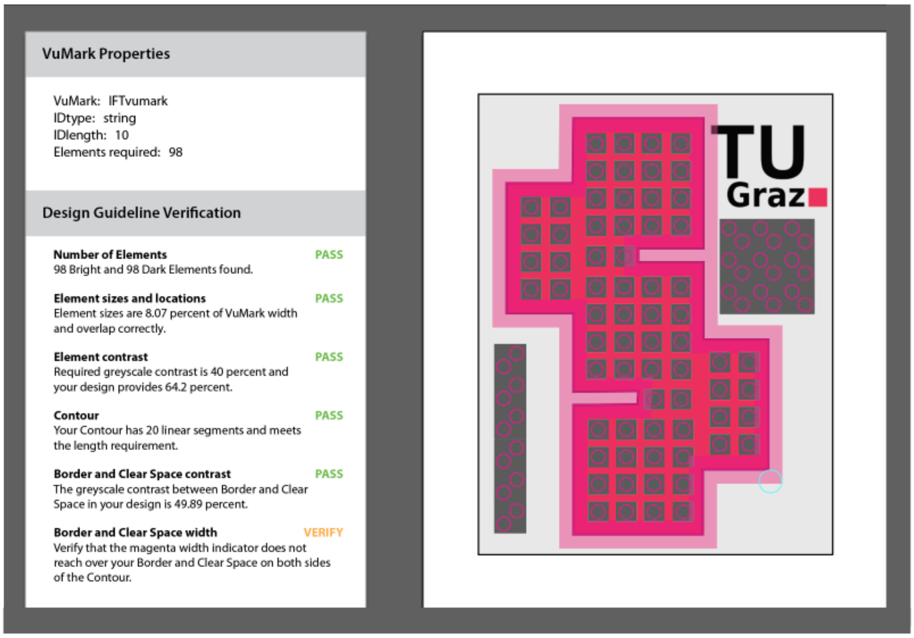

Figure 5.5.: Vumark Design Template

and the clear space has to be more than 40%. Afterwards the bright and dark elements have to be created. The same size is required for all elements. The bright and dark elements must overlap correctly and also a contrast of more than 40 % is needed.
Our VuMark consists of the type string and an ID length of 10. That leads to an amount of 98 elements. After the creation process in the Illustrator, the VuMark gets processed in Vuforias Target Manager. The VuMark generator chooses randomly dark and light squares to create a unique VuMark. The final VuMark is shown in Figure 5.6.

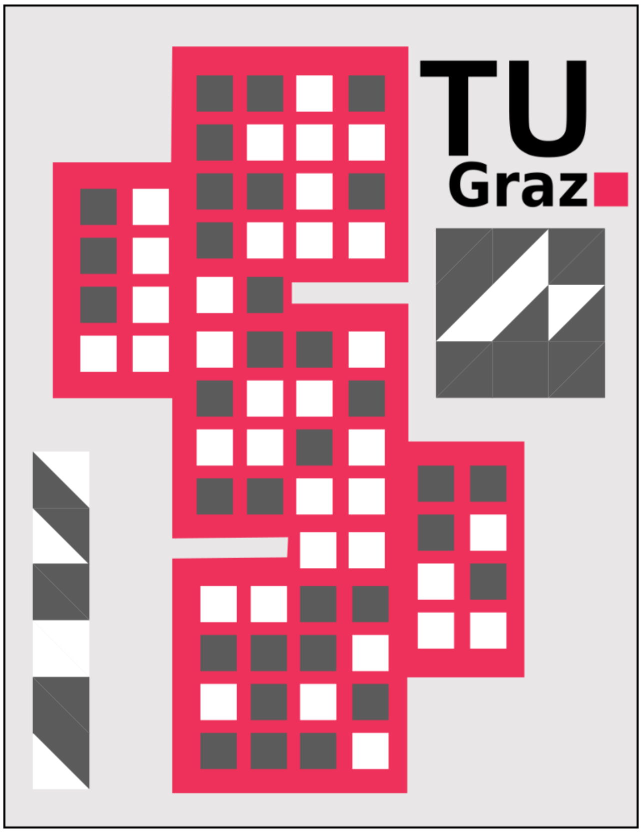

Figure 5.6.: VuMark used in the Case Study

5.2.4. Control Methods

For the control of AR apps two different types of buttons exist. For one thing, virtual buttons exist, then again the classic UI buttons can be used as well. Virtual buttons are a special type of buttons used for AR, VR and similar 3D based scenes. For AR, they are usually designed as a rectangle and are placed on the marker. It is an interesting feature, but probably it is more interesting for HMDs. For HHDs virtual buttons have been tested and the result was, that they have to be larger than normal UI buttons to be clickable. Virtual buttons need usually more than two fingers to click and to match the button exactly with the fingers requires some training.

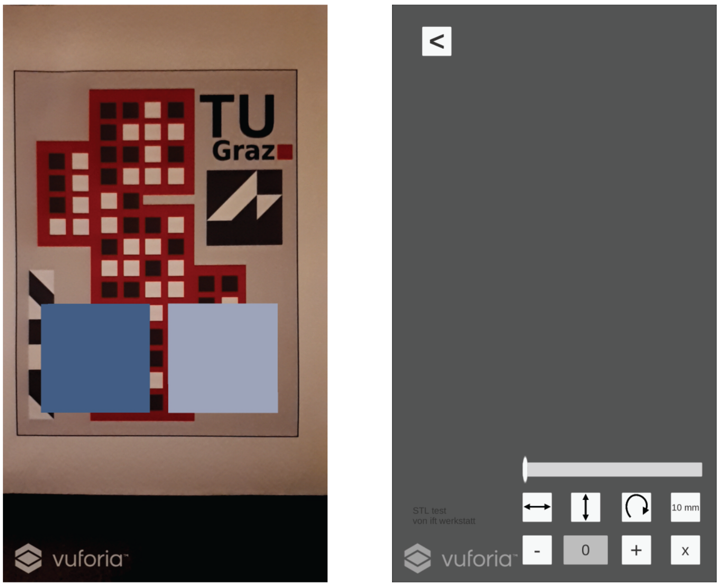

Figure 5.7.: Comparison of virtual and UI buttons

For the collision detection we need seven buttons to position and rotate the virtual component. With virtual buttons, too much of the VuMark would be overlaid or otherwise, a huge marker would be necessary. According to that the decision was made in favour of UI buttons. These buttons can be much smaller, so they wouldn't conceal much of the content. Furthermore buttons on the screen are much easier to click. Figure 5.7 shows a comparison of both button types. The left side shows the virtual buttons and on the right side a screenshot of the AR app with UI buttons can be seen.

5.2.5. Data Types for 3D Models

For different sectors, varying data types for depicting 3D models are used. The IFT is working with SolidWorks for constructing and editing 3D models of different components. The standard export format of SolidWorks is *.sldprt*, but also export to *.stl* and *.step* is possible.
Unity doesn't accept any of these file formats, instead it supports *.fbx, .dae (Collada), .3ds, .dxf, .obj, and .skp.* (Unity, 2018b) The interesting fact is, that Unity is showing the models in *.fbx* format, so importing in another format results in a conversion to *.fbx*.
Even though it is not mentioned in the manual, Unity supports another format called *GLTF* or *GLB* as binary variant. *GLTF* is a relatively new format announced in late 2015. It tries to create a new standard for 3D scenes and calls itself the *"JPG of 3D"* (Khronos, 2018).
Figure 5.8 shows an overview of the format. It consists of a *.gltf* file, a *.bin* file and textures in the format of *.png* or *.jpg*. The *.gltf* file is actually a JSON file, which includes the node hierarchy, material textures and cameras. The ".bin" file contains the geometry of a 3D model including vertices and indices, furthermore animations and skins. That content can be also exported as *.glb* file, which is a binary form of *.gltf*. The difference is, that textures are included and not attached as external images. (Khronos, 2018)

For the AR app different data types have been verified before one of them was selected. The format *.obj* didn't remain stable in AR applications. It started flickering or even disappeared quite fast. *3DS* had a more stable behaviour, but it didn't achieve the stability of *FBX* files. GLTF files achieved the same stability as *FBX* in practical tests.

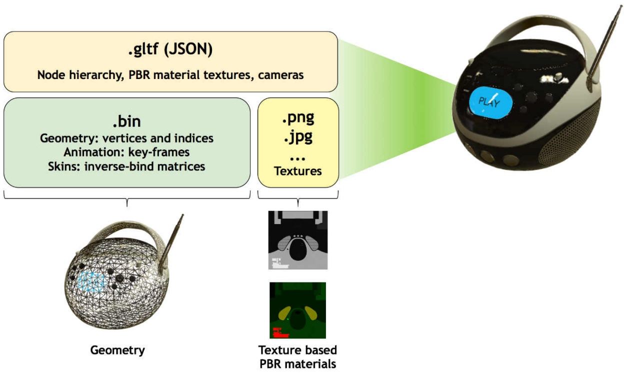

Figure 5.8.: GLTF2 Standard (Khronos, 2018)

5.2.6. Repository for Model Selection

The biggest challenge during the implementation phase of the AR app was the import function at runtime for 3D models. Unity and Vuforia don't provide any built-in function to achieve this goal. Only a few paid importers are available in Unitys Asset Store, where just some 3D formats are supported and almost no documentation is available. Furthermore importing 3D models with Unitys *WWW* interface doesn't seem like a solution, because the whole mesh of the 3D object needs to be recalculated on someones own. By searching for runtime import possibilities, the article of Kraakman (Kraakman, 2018) seemed promising. He decided to use the GLTF standard, because the runtime importers of Unitys asset store were only partially supporting the desired formats. He was also referring to Sketchfab, which supports *GLTF*.
When dealing with the *GLTF* concept, the Khronos Group listed different repositories, which support the file format. That are TurboSquid, Sketchfab, Google Poly and Remix 3D. (Khronos, 2018) Unfortunately only two of them - Sketchfab and Google Poly - provide an API to import 3D models at runtime in Unity. The next requirement for the import was, that the assets have to be private and not publicly accessible for all other users. Sketchfab offers private assets only for paid accounts, so that repository was excluded. (Sketchfab, 2018) Fortunately, Google Poly is a free tool, which works with the Creative Commons license. That means public assets can be remixed, but the modifier has to give attribution to the original author. (Poly, 2018)

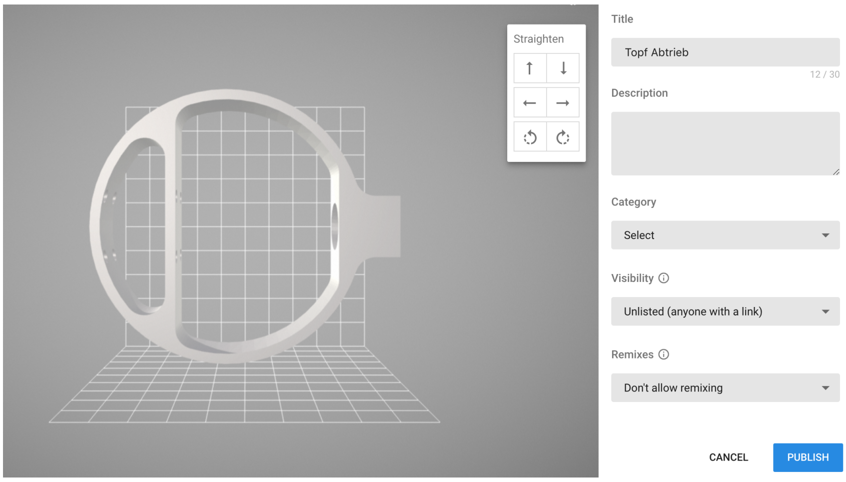

Figure 5.9.: Google Poly (Poly, 2018)

For the reasons mentioned before Google Poly was chosen as the repository for 3D assets. It provides an online platform to upload 3D models and an API to fetch it at runtime. Figure 5.9 shows the publishing and editing form of Google Poly. A name, a description and a category can be assigned and the user is able to set the asset to *not listed*, which means, it is not accessible by anybody else except if they know the exact link. Furthermore the asset can be rotated around all three axes.
The API provides functions to list and import assets at runtime. The runtime import can select between searching for default categories, *UserAssets* and *LikedAssets*. In the background Poly is recalculating the meshes of the imported assets. Furthermore Poly has OAuth 2.0 implemented for desktop applications.

5.2.7. OAuth

OAuth 2.0 is a common protocol for authorization, which is also used by Google APIs. Therefore a ClientID and a ClientSecret are needed, which can be obtained at the Google API console. These credentials are sent to the

server to login and to get an *Authorization Code* returned. The *Authorization Code* is forwarded again to retrieve the *Access* and *Refresh Token*, which are needed to call a particular API. (Google, 2018)
Figure 5.10 gives an overview of the process. For the usage within an Android app the OAuth implementation of the Poly API had to be extended.

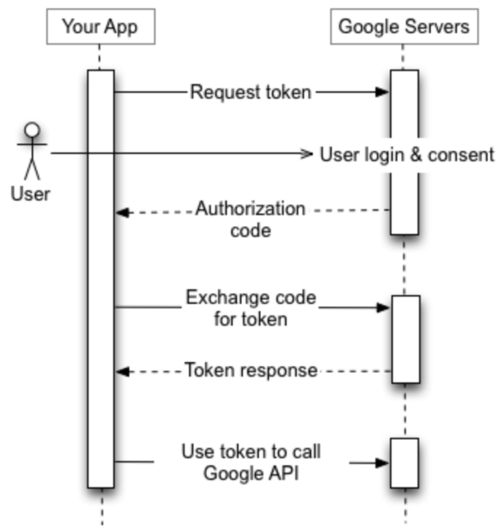

Figure 5.10.: OAuth 2.0 (Google, 2018)

5.3. Implementation Details

The following section shows a few implementation details for the collision detection app. It is split up into Unity-related peculiarities, API calls and processing of 3D models.

5.3.1. Unity-related Peculiarities

In comparison to other development environments Unity has a few special features. In general, it works with scenes. A scene is an own view with different game objects, where scripts are attached to define the behaviour. As Unity is primarily used for game development, each scene represents a level. Furthermore a camera is a mandatory component for each scene. It is used to display the game world. More cameras are possible, if different views of the game are necessary. Moreover, Unity distinguishes between 2D and 3D. UI-Elements are developed in 2D mode, where a Canvas is used as a container for different elements. (Unity, 2018b)
After explaining a few overall characteristics of Unity, two development concepts, which were used for the implementation of the AR app, will be explained in detail.

Prefabs

A *Prefab* is a template for a game object, which is created at design time and it lets you generate game objects at runtime with exactly that properties. (Unity, 2018b) It is helpful, if a component is reused several times in an application. Furthermore it is possible to specify the values of the template during runtime.
That concept was used to display and create the *AssetList* for the model selection. Therefor a *Prefab* with a button as main element was created. It has a *RawImage* and a *Text* component as children. These two fields are edited during the query to return a complete list with clickable items. The usage of this approach is explained in section 5.3.2, whereby Figure 5.13 shows the implementation.

IEnumerator and Coroutines

Unity can be seen as a single threaded application, which implies that only one main thread is available for all executions. Furthermore Unity is frame-based, which means that it works with "frames per second" (FPS). With that technique it can happen, that one process actually needs more frames to finish, which leads to the result, that at that time, the program is running at low FPS. In the worst case the program is freezing for a short time. To avoid this problem coroutines can be used. A coroutine can stop the method execution at predefined points and continue exactly at this status again. It resumes when a special condition is met. Stop conditions are usually set with the "yield" statement. (Unity, 2018b)

```
    IEnumerator LoadTextureFromUrl(string URL, int newtag)
{
    //Request texture from Server
    WWW www = new WWW(URL);
    while (!www.isDone)
    {
        Debug.Log("Download texture on progress: " + www.progress);
        yield return null;
    }

    if (!string.IsNullOrEmpty(www.error))
    {
        Debug.Log("Download failed");
    }
    else
    {
        Debug.Log("Download succes");
        Texture2D texture = new Texture2D(1, 1);
        texture.LoadImage(www.bytes);
        texture.Apply();

        //Retrieve number of actual Gameobject and apply texture
        buttontag = newtag.ToString();
        GameObject.FindWithTag(buttontag).GetComponentInChildren<RawImage>().texture = texture;
    }
}
```

Figure 5.11.: Coroutine for fetching textures of assets

Coroutines are typically used for asynchronous execution such as network requests, if code needs to be executed over several frames or for animations. In comparison to coroutines the update function isn't checking the status all the time and would just perform the animation. Update is usually called 4 times per frame. That would be an unnecessary use of CPU. With coroutines

it is possible to specify a special amount of time, until the coroutine runs again.(Gesote, 2018)
A coroutine was used for the network request to fetch the textures of the assets from the server. Figure 5.11 shows the implementation. The method call of the coroutine requires two values: the URL of the asset and the tag of the object, that the texture can be assigned to the correct item later. For the download of the texture the yield statement is used in the while loop, that the program doesn't wait for the download to be finished to continue with other processes.

5.3.2. Calls from Poly API

In order to obtain 3D models from Google Poly a few API calls were necessary. Therefor the process consists of three steps until the asset is downloaded:

1. Login of the user via API
2. Retrieval of the *AssetList*, where the user can choose the 3D model
3. Server request with the URL from the asset to fetch a particular 3D model

These last two steps will be explained in the following section in detail.

List UserAssets

The Poly API provides a function to retrieve lists of 3D models. They distinguish between *UserAssets*, *LikedAssets* and the standard asset request, where a category can be chosen. For *UserAssets*, different visibility variants can be selected. For the *ListAssets* function a callback is typical, which includes the implementation of the handling of the returned results. Figure 5.12 shows the request and Figure 5.13 shows the callback for fetching the data of the *AssetList*. In the callback, list items are created from a *Prefab* called *Button*. That includes a *Button*, a *RawImage* and a *Text*. The text was overwritten with the assets name and the *RawImage* contains its texture. In the function itself a *ClickHandler* for the button was added to open the AR scene and transmit the URL for fetching the 3D model.

```
PolyListUserAssetsRequest request = new PolyListUserAssetsRequest
{
            // Sorting of the retrieved assets
    orderBy = PolyOrderBy.NEWEST,
    //Show only published results, both public and not listed
    visibility = PolyVisibilityFilter.PUBLISHED,
    // Amount of results, max. 20 per page
    pageSize = 20
};
// Send the request.
PolyApi.ListUserAssets(request, AssetListCallback);
```

Figure 5.12.: API Call to list UserAssets

```
void AssetListCallback(PolyStatusOr<PolyListAssetsResult> result)
{
    if (!result.Ok)
    {
        Debug.Log(result);
    }
    // result.Value.assets is a list of Assets.

    searchtext.GetComponent<Text>().text = "Sie haben " + result.Value.totalSize + " Suchergebnisse";
    searchtext.gameObject.SetActive(true);

    foreach (PolyAsset asset in result.Value.assets)
    {
        tag++;
        //create the Prefab Button for a dynamic list and tag it for proper identification
        newObj = (GameObject)Instantiate(Button, transform);
        newObj.gameObject.tag = tag.ToString();
        // Error Handling: if one of the necessary values is null, show an error message
        if ( asset.thumbnail.url == null || asset.displayName == null|| asset.name == null){
            errortext.GetComponent<Text>().text = "Komponete Nummer " + tag + " hat fehlerhafte " +
                "Werte. \n" + "URL des Bildes" + asset.thumbnail.url + "\nNames des Bildes" +
                asset.displayName + "\nPfad des Modelles:"+ asset.name +
                "\nBitte löschen Sie das Bild von Google Poly und laden Sie es erneut hoch";
            break;
        }

        //get the URL of the texture
        url = asset.thumbnail.url;
        //Call a coroutine to load the image of the 3D-modell
        StartCoroutine(LoadTextureFromUrl(url,tag));

        //Display the name of the asset
        newObj.GetComponentInChildren<Text>().text = asset.displayName;

        //Create a temporary Button Gameobject to add a ClickListener for each Button.
        Button temporButton = newObj.GetComponent<Button>();
        string tempstring = asset.name;

        temporButton.onClick.AddListener(delegate { ButtonClicked(tempstring); });

    }
}
```

Figure 5.13.: Callback of UserList

Fetch and Import Assets

For the import of assets the particular URL is needed for the network request. Therefor we had to pass it from the *List* script to the *Import* script. Here a callback is used again, as shown in Figure 5.14. The callback function tests, if the result is okay and afterwards a few import options can be defined. Figure 5.15 shows the import settings.

```
public void Start()
{
    //Requesting the 3D model at start of the scene
    assetpath = ShowAssetList.path;
    //Request funtion including callback
    PolyApi.GetAsset(assetpath, GetAssetCallback);
    statusText.text = "Requesting...";
}
```

Figure 5.14.: Requesting Asset

```
private void GetAssetCallback(PolyStatusOr<PolyAsset> result)
{
    if (!result.Ok)
    {
        //Show error message
        statusText.text = "ERROR: " + result.Status;
        return;
    }

    // Set the import options.
    PolyImportOptions options = PolyImportOptions.Default();
    //Scale factor of 3D-model
    options.scaleFactor = 0.1f;
    //Center Asset
    options.recenter = true;

    statusText.text = "Importing...";
    PolyApi.Import(result.Value, options, ImportAssetCallback);
}
```

Figure 5.15.: Import Asset

5.3.3. Processing of 3D models

For the AR-part of the application the 3D models have to be processed to display them at the VuMark. Furthermore at runtime it is necessary to move and rotate the 3D model.

Usage of imported Assets for AR

When retrieving the asset from the importing function, it is only a game object, which is hovering somewhere in the application. In order to show and call it properly, a few settings have to be made before. First, the tag of the game object needs to be set, to have an unique identifier. Second, it needs to be a child of the VuMark, especially the *TrackableBehaviour*, otherwise it wouldn't be shown with AR. Finally, the position and scale are set, before the game object is set visible. Figure 5.16 shows the script for these tasks.

```
// Show attribution (asset title and author).
statusText.text = asset.displayName + "\nvon " + asset.authorName;

//set tag of 3D model to be able to control it from other scripts
result.Value.gameObject.tag = "move";

GameObject trackableGameObject = theTrackable.gameObject;

//disable any pre-existing augmentation
for (int i = 0; i < trackableGameObject.transform.childCount; i++)
{
    Transform child = trackableGameObject.transform.GetChild(i);
    child.gameObject.SetActive(false);
}

// Re-parent the model as child of the trackable gameObject
result.Value.gameObject.transform.parent = theTrackable.transform;

// Adjust the position and scale of the  model
result.Value.gameObject.transform.localPosition = new Vector3(0, 0.2f, 0);
result.Value.gameObject.transform.localRotation = Quaternion.identity;
result.Value.gameObject.transform.localScale = new Vector3(0.1f, 0.1f, 0.1f);

// Set it active
result.Value.gameObject.SetActive(true);
```

Figure 5.16.: Preparation of Asset for AR

Scaling of 3D models

For production it has a high importance that the 3D-models which are shown have exactly the correct size. Unity works with "scene units", which is not really a standardized measurement unit. Instead a scene unit is relative to the marker to be tracked. Vuforia requires the width of the marker to calculate its height. The VuMark used for the application has a width of 11cm, which yields a height of 14,2835cm. Then Unity uses the height as a scaling factor. That means for new game objects the height is 1 in scene units, if they are as long as the height of the markers. With that information it is possible to convert into centimeters and millimeters. In our app, 1 centimeter is represented by 0.070010851682 scene units.

Movement of 3D models

Figure 5.17 shows the positioning of game objects with buttons. If a button is clicked, the method for the movement is called. Here the structure *Vector 3* is called and thereby positions and directions can be changed. The value is changed accordingly to the scene units, that the object is moved exactly the desired amount. Furthermore the real value in millimeters is shown in a blank field in the app.

```
case "x":

    GameObject.FindWithTag("move").transform.localPosition += new Vector3(minusdistance, 0, 0);
    positionx -= value;
    Value.GetComponentInChildren<Text>().text = positionx.ToString();
```

Figure 5.17.: Positioning of 3D models

Rotation with Quaternion.Euler

For the rotation functionality buttons and a slider have been implemented. The buttons are used for the coarse rotation, each click rotates by 90 degrees. The slider is able to rotate the game object exactly within the range of 90 degrees.

For the implementation *Quaternion.Euler* was used, which allows to turn objects along the x,y and z axes. *Quaternion.Slerp* lets users rotate from a special starting angle to a defined angle. As already mentioned in section 5.3.1, coroutines can be used for animations. In order to keep the rotation smooth, it was implemented with a coroutine. The following script shows the call of the coroutine, which is displayed in Figure 5.18. As one can see, the coroutine for the rotation requires two parameters. The first one defines the direction and how much degrees it should be rotated and the second value is the interval of rotation.

*StartCoroutine(Rotation(Vector3.left * 90, 0.8f));*

```
IEnumerator Rotation(Vector3 byAngles, float inTime)
{
    var startAngle = transform.rotation;
    var toAngle = Quaternion.Euler(transform.eulerAngles + byAngles);
    for (var t = 0f; t < 1; t += Time.deltaTime / inTime)
    {
        GameObject.FindWithTag("move").transform.rotation = Quaternion.Slerp(startAngle, toAngle, t);
        transform.rotation = toAngle;
        yield return null;
    }
}
```

Figure 5.18.: Rotation of 3D models

5.4. Practical Tests and Outcomes

At the end of this master's thesis, an AR application for collision detection was the result after several feedback rounds and some challenges during the implementation. The final application includes a runtime import, the model selection and many more features, which have been explained in section 5.3. Therefor the first part of this chapter will show some visual insights into the app.
Furthermore the application was presented to the management of the IFT and to the workshop of the institute. Therefor the whole process has been explained, how a 3D-model is processed to appear in the model selection list in the app, how the model is selected and finally, how it is shown on the VuMark.

5.4.1. Visual Insights

The section 5.1.3 showed already a storyboard including Mock-Ups to point out how the final application will look like. This concept was upheld during the implementation, but it has been extended in some points.
Figure 5.19 shows the model selection on the left side and the AR scene on the right side. The model selection was enhanced with a login button to retrieve private assets and a button to show the assets, that the user is able to update the list independently.
Furthermore the amount of search results is shown at the top and the design of the list was slightly changed. The whole light grey rectangle serves as a button and instead of a simple "select" command the name of the object is shown. Furthermore an error message will be shown, if parts of the data of a 3D model are corrupted, that the user knows, when a renewed upload to Google Poly is necessary.
The right side contains the AR scene, where a virtual object is shown on a VuMark and all control mechanisms are enabled. The basic concept of the control mechanisms for the virtual object was already defined in the storyboard, but it was refined to a achieve a more precise result. The movement along all three axes stayed almost the same, but the measurement

unit was changed from centimeters to millimeters. Furthermore a button was added to change the value of the measurement unit. The chosen interval is 1, 5, 10 and 100mm.
For the rotation a button for each axis exists, which rotates exactly at the range of 90 degrees. Despite that, a slider is available for a fine rotation within 90 degrees.
The button containing a x in the lower right corner serves as a changer for the axes. If it is tapped, it switches to y or z. The changing function works for both movement and rotation. For the rotation the slider is turning around the selected axis.
The text box in the lower left corner contains the name of the object and the uploader. During import time, the status of the import is displayed and in case of failure an error message is shown.

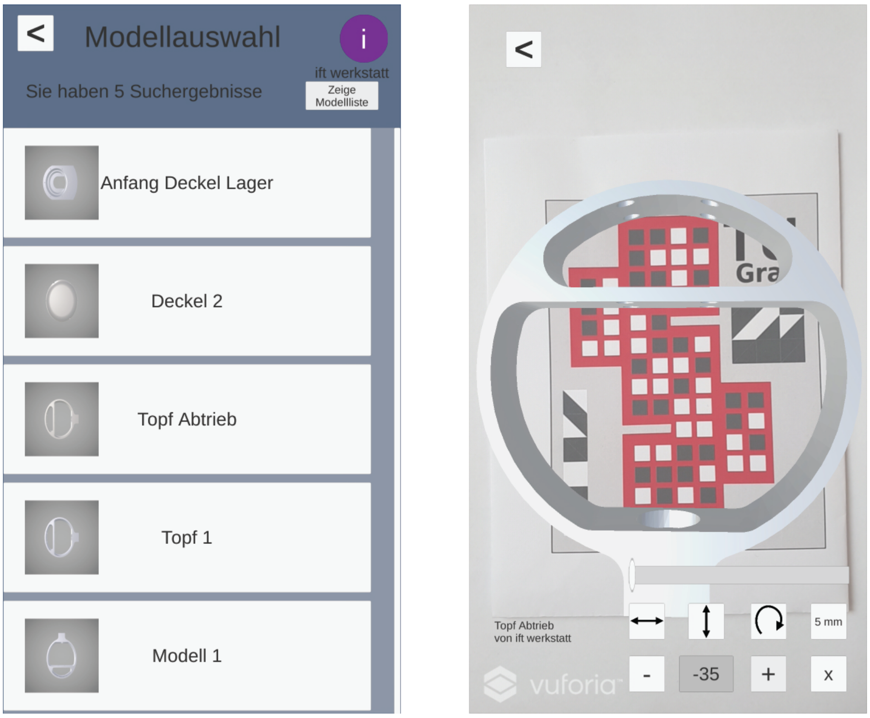

Figure 5.19.: Final AR Application

5.4.2. Practical Tests

The final application was shown to the end-users, which are primarily the workshop of the IFT and additionally to the management of the IFT to consider different perspectives.
The application was shown independently to both parties, so the feedback section is divided into two parts. All in all a positive response was received and all participants were interested in trying out a new technology.

Feedback from the Head of IFT

At a late stadium of this master's thesis, the application was presented to the management of the IFT. During the presentation the whole process from uploading a 3D model until it is displayed on a VuMark was demonstrated. Although the presentation didn't fully succeed due to an error, the response of the institute was, that the use case has a high relevance for production, because complications can occur in that area. The precise scaling is enormously important to see possible collisions. A wrong scaling would lead to incorrect results. Therefor a detailed description of the calculation of scaling was added in chapter 5.3.3.
An additionally interesting concept would be a function to select clamping devices as well. There it would be useful to select a clamping device and add it below the 3D model. For that enhancement, a 3D model with the exact measurements of the clamping device would be necessary, because the shift of the virtual workpiece needs to be calculated precisely.
For the future it would be beneficial to use also 3D scans of workpieces instead of constructed parts, which are made for example with SolidWorks. A 3D model might not be available for each component, so there it would be an enhancement to be able to scan it. But for that application idea, 3D scans need to be improved, that the result is more accurate.

Feedback from the Workshop

The other evaluation was performed with the employees of the workshop of the IFT. Here the focus was set on the practical usage of the AR app, but the upload process was shown as well.
The employees tried out the application, viewed the virtual object from different perspectives and tested the control mechanisms. Their idea was that also a tablet would be practical as a device, because the display is a little bit bigger. For the collision detection app it would be possible to use it also on a tablet, the single requirement is the operating system, which has to be Android.
For testing purposes during development time the chosen measurement unit were centimeters. Their feedback was, that in production millimeters are more common. So in the application the measurement unit was changed and furthermore users can choose different values to achieve an easier positioning.
The VuMark was printed on water- and tear-resistant paper, because a normal print would be unusable quite fast because of wet or filthy spots inside the machine. But a piece of paper can't be clamped directly, it just could be put inside the machine. Therefor it would be handy, if the VuMark is fixed to a thin plastic or wooden plate, because by this it is possible to clamp it.
For an easier rotation, it would be helpful, if a coordinate system with at least the x and y axis is shown at the object. The realization of such a function could be slightly complex. The virtual object is 3D and different objects have various depths. The coordinate system for x and y would be only 2D. It is possible to show a coordinate system above the model and rotate it, but with the varying depths of the virtual workpiece, there would be a high calculation effort because of the center of rotation.

6. Conclusion

Technology is developing in a fast pace nowadays. Every day, new applications appear on the market, new hardware is developed and supports people in their daily situations in a different and innovative way. In order to create sustainable development, the whole development process of technology and how people are influenced in their everyday interaction have to be questioned.
The present study sets its focus on future-oriented concepts such as how to achieve responsible and sustainable processes and on investigating the impacts of computer supported collaboration, before concentrating on Augmented Reality. The aim was to develop an application for collision detection for milling machines, whereby responsible development played an important role.
The first big topic was Responsible Research and Innovation. In that chapter, past trends such as Computer Ethics and Codes of Conduct were outlined to illustrate the emergence of RRI. Thereafter, a definition and an explanation of RRI was provided and several research fields have been mentioned, where RRI was already applied and in which manner. A significant importance had the classifications of RRI, which include the different concepts of Stilgoe, Jirotka and the European Commission. The last section in this chapter focused on frameworks for RRI, which comprised specialized tools for ICT and general tools, for example the RRI tool cards, which are similar to a conversation guideline to direct the discussion to certain topics.
The ensuing chapter dealt with Computer Supported Collaborative Work, a concept about how the collaboration of people is influenced and supported by technology. The CSCW matrix has been explained, which classifies collaboration tools and methods into asynchronous or synchronous usage and on-site or remote location. Thereby four quadrants emerge. Different classic communication technologies such as audio or video conferences, wall displays and emails have been assigned to the particular quadrants.

Furthermore new collaboration methods have been explained, for instance pair programming, Wikis, online courses or shared editors. In addition a connection to the quadrants was established. The section concluded with collaborative AR applications. Thatfor a well-known example for manufacturing was the provisioning of instructions for maintenance or service tasks with the help of AR.
The third chapter provides an introduction about Augmented Reality. It started with a comparison about Augmented Reality, Mixed Reality and Virtual Reality to be able to distinguish between different kinds of realities. Afterwards, different methods have been outlined how content can be detected to overlay it with additional information. Those were marker-based and markerless, location and recognition-based AR. Later on an overview about different devices was given. It included head-mounted and hand-held devices, projectors and magic mirrors. Another part contained information about different SDKs for AR. Subsequently, different existing AR applications for manufacturing have been reviewed.
The practical part of this master's thesis contained the implementation of an AR app for collision detection for milling or drilling machines. Therefore different prerequisites from the workshop have been discussed in the first place before they were rephrased into requirements for the implementation. Moreover a connection between the use case and both topics RRI and CSCW has been established. It described practices, how RRI can be used for the collaboration with a workshop in a production environment.
The part about the technical realization focused on the reasons why a particular SDK, device and platform were selected. Vuforia with Unity was chosen as development platform and the devices to be supported were Android smartphones. Beside that, the import of 3D models was one of the major challenges in this section. Different data types for 3D objects have been analyzed and tested for their stability. When the decision was taken to use *GLTF* for the representation, different repositories and toolkits were examined to find an answer on how to solve the challenge of the runtime import. Google Poly was the final choice, because it is free of charge and supports Unity. In order to provide a short insight into the development of the app, a few implementation details have been described. They were divided in three sections:

1. Unity-related features, such as *Prefabs* and *Coroutines* have been clari-

fied and also for which cases it was implemented.
2. Several API Calls have been presented to give a short overview of their usage.
3. The processing of 3D assets was illustrated, such as the converting of the 3D asset to be shown in AR and different positioning and rotation functions.

The last section of the practical part contains the practical test and its outcomes. At first, two screenshots of the main functions of the application were attached to provide a comparison between the wireframes used in the storyboard and the final application. All the functions have been explained in detail to give also an overview of how to operate the application.
Furthermore the AR application was presented to the employees of the workshop and the management of the IFT independently to gain final feedback from end-users. In general the feedback was positive and all people liked to try out the AR app and view the model from different perspectives. Small enhancements have been suggested, for instance changing the measurement unit to millimeters. For future advancements there were several ideas for adding further features. One was a selection of virtual clamping devices, which would be shown below the 3D object.
In general the collaboration with the workshop was an interesting experience. It was very useful to get feedback during development time, which improved the implementation process enormous.
In context of RRI, it was interesting to see and conduct the information and inclusion process. For this use case it felt very important, that all involved persons have a similar knowledge about the technologies, which will be introduced in future and that the delimitation to other similar technologies was given. Workers benefit from that knowledge in that manner to have more realistic expectations and to be aware, what is approximately possible with the technology. In contrary also the developer has to have a basic knowledge about the machines, how they are working and rotating. That helps to give advice about what is supported by the chosen technologies.
For that use case, the distinction between Augmented and Mixed Reality was really important, since the border between both technologies is blurred. After some time a common consensus was found which machine is suitable for the use case. The outcome was, that a 3-axis machine was chosen. Collision detection can't be performed with AR at a 5-axis machine, because

the VuMark for detection would be invisible after some time because of the extended rotation possibilities. Without the marker AR can't overlay anything anymore. But the 5-axis machine can be interesting for future projects.
As a future outlook it would be interesting to introduce Mixed Reality into the workshop as well. Since the collision detection with Augmented Reality was only possible for 3-axes machines and not for 5-axes machines, it would be interesting to enhance the concept with Mixed Reality. Thereby the challenge with loosing the VuMark or Image target could be solved, because Mixed Reality usually works with anchors. But still, there is the question of stability.
For Augmented Reality, the runtime import of 3D models will be still an interesting topic for the future. There is the need to define standards to achieve a more consistent procedure. Despite that, there is still a demand to improve detection methods, that also objects can be identified easier and there is no need for Image Targets or VuMarks printed on paper anymore.
Finally, Augmented Reality is an interesting and promising technology to improve the workflow in certain environments. Especially with hand-held devices it got more accessible to the wider public. For the future, AR applications for smartphones have to become more stable and AR glasses have to decrease their price, to achieve a higher utilization of AR in the daily life of people. Furthermore more easy-to-use AR applications such as Pokemon GO or Snapchat would help to increase the pervasiveness of AR.

Bibliography

ACM (1966). *Guidelines for Professional Conduct in Information Processing (1966)*. URL: https://ethics.acm.org/code-of-ethics/previous-versions/1966-acm-code/ (visited on 06/01/2018) (cit. on p. 9).

ACM (1972). *ACM Code of Professional Conduct (1972)*. URL: http://ethics.acm.org/code-of-ethics/previous-versions/1972-acm-code/ (visited on 06/01/2018) (cit. on p. 9).

ACM (1992). *1992 ACM Code of Ethics and Professional Conduct*. URL: http://ethics.acm.org/code-of-ethics/previous-versions/1992-acm-code/ (visited on 06/01/2018) (cit. on pp. 9, 12).

ACM (2018). *Code 2018 Project*. URL: https://ethics.acm.org (visited on 06/01/2018) (cit. on p. 9).

Amin, Dhiraj and Sharvari Govilkar (2015). "Comparative study of augmented reality SDKs." In: *International Journal on Computational Science & Applications* 5.1, pp. 11–26 (cit. on pp. 56, 57).

Apple (2018). *Purchase and Activation*. URL: https://developer.apple.com/support/purchase-activation/ (visited on 11/30/2018) (cit. on p. 75).

ARCore (2018). *ARCore Overview*. URL: https://developers.google.com/ar/discover/ (visited on 11/11/2018) (cit. on pp. 56, 74).

ARKit (2018). *ARKit*. URL: https://developer.apple.com/arkit/ (visited on 11/11/2018) (cit. on pp. 56, 74).

AugmentedMinds (2017). *Endgeräte für AR / MR*. URL: https://www.augmented-minds.com/de/erweiterte-realitaet/augmented-reality-hardware-endgeraete/ (visited on 09/12/2018) (cit. on pp. 53–55).

BCS (1978). *Code of Practice(1978)*. URL: http://ethics.iit.edu/ecodes/node/3106 (visited on 07/06/2018) (cit. on p. 10).

BCS (2015). *BCS Code of Conduct*. URL: https://www.bcs.org/category/6030 (visited on 07/05/2018) (cit. on pp. 10, 12).

Billinghurst, Mark and Hirokazu Kato (July 2002). "Collaborative Augmented Reality." In: *Commun. ACM* 45.7, pp. 64–70. ISSN: 0001-0782. DOI: 10.1145/514236.514265. URL: http://doi.acm.org/10.1145/514236.514265 (cit. on pp. 42, 43).

Billinghurst, Mark, Suzanne Weghorst, and T. Furness (1998). "Shared space: An augmented reality approach for computer supported collaborative work." In: *Virtual Reality* 3.1, pp. 25–36 (cit. on pp. 43, 57).

Brewster, Kat (2016). *Pokémon Go review: not a good game... but a great experience*. URL: https://www.theguardian.com/technology/2016/jul/12/pokemon-go-review-it-may-not-be-a-good-game-but-its-a-great-experience (visited on 11/10/2018) (cit. on pp. 49, 52).

Bunk-Art (2016). *Bunk Art AR APP*. URL: https://play.google.com/store/apps/details?id=al.dev.bunkart&hl=en_US (visited on 08/24/2018) (cit. on pp. 42, 43, 58).

Burget, Mirjam, Emanuele Bardone, and Margus Pedaste (2017). "Definitions and conceptual dimensions of responsible research and innovation: A literature review." In: *Science and Engineering Ethics* 23.1, pp. 1–19 (cit. on pp. 15, 28–30).

Büttner, Sebastian et al. (2017). "The Design Space of Augmented and Virtual Reality Applications for Assistive Environments in Manufacturing: A Visual Approach." In: *Proceedings of the 10th International Conference on PErvasive Technologies Related to Assistive Environments*. PETRA '17. Island of Rhodes, Greece: ACM, pp. 433–440. ISBN: 978-1-4503-5227-7. DOI: 10.1145/3056540.3076193. URL: http://doi.acm.org/10.1145/3056540.3076193 (cit. on p. 60).

Callon, Michel, Pierre Lascoumes, and Yannick Barthe (2009). *Acting in an Uncertain World: An Essay on Technical Democracy*. The MIT Press. ISBN: 0262033828 (cit. on p. 29).

Carvalho, Aparecido de et al. (May 2018). "Of Embodied Action and Sensors: Knowledge and Expertise Sharing in Industrial Set-Up." In: *Computer Supported Cooperative Work (CSCW)* 27. DOI: 10.1007/s10606-018-9320-6 (cit. on pp. 42–45, 57).

Dasey, Daniel (2017). *Try before you buy: New IKEA Place app makes home furnishing easier*. URL: https://highlights.ikea.com/2017/ikea-place/ (visited on 11/10/2018) (cit. on p. 52).

Doodle (2018). *Doodle*. URL: https://doodle.com/ (visited on 08/28/2018) (cit. on pp. 41, 42).

ECSITE (2016). *RRI Toolcards*. URL: https://www.ecsite.eu/sites/default/files/rri_tools_cards.pdf (visited on 08/15/2018) (cit. on p. 34).

Eden, Grace, Marina Jirotka, and Bernd Stahl (2013). “Responsible research and innovation: Critical reflection into the potential social consequences of ICT.” In: *Research Challenges in Information Science (RCIS), 2013 IEEE Seventh International Conference on*. IEEE, pp. 1–12 (cit. on pp. 15, 16, 20, 21, 24–27).

EPSRC (2013). *Anticipate, reflect, engage and act (AREA)*. URL: https://epsrc.ukri.org/research/framework/area/ (visited on 08/15/2018) (cit. on p. 34).

EuropeanCommission (2012). *Responsible Research and Innovation: Europe's Ability to Respond to Societal Challenges*. Publications Office of the European Union (cit. on pp. 22–24).

FFG (2011). *FFG: Horizon 2020*. URL: https://www.ffg.at/europa/h2020 (visited on 08/11/2018) (cit. on p. 14).

Friedrich, Wolfgang, D Jahn, and L Schmidt (2002). “ARVIKA-Augmented Reality for Development, Production and Service.” In: *ISMAR*. Vol. 2002. Citeseer, pp. 3–4 (cit. on pp. 54, 59, 60).

FRRIICT (2012). *FRRIICT Oxford workshop*. URL: https://philosopher1978.wordpress.com/2012/06/20/frriict-oxford-workshop/ (visited on 08/17/2018) (cit. on pp. 26, 32).

Fruend, J. and C. Matysczok (2002). “Designing flexible manufacturing systems with augmented reality.” In: *Augmented Reality Toolkit, The First IEEE International Workshop*. IEEE, 3 pp. (Cit. on p. 59).

Gadbois, Serge (2015). *Responsible Innovation Diagnosis in ICT*. URL: http://test4.net/cfi/ (visited on 08/15/2018) (cit. on pp. 32, 33).

Gesote, Redra (2018). *Mastering Coroutines in Unity in 10 mins*. URL: http://www.theappguruz.com/blog/how-to-use-coroutines-in-unity (visited on 11/30/2018) (cit. on p. 86).

Google (2018). *Using OAuth 2.0 to Access Google APIs*. URL: https://developers.google.com/identity/protocols/OAuth2 (visited on 11/15/2018) (cit. on p. 83).

Gross, Tom and Michael Koch (Jan. 2007). *Computer-Supported Cooperative Work*. ISBN: 3486580000 (cit. on pp. 40–42).

Gurzawska, Agata, Markus Mäkinen, and Philip Brey (2017). “Implementation of Responsible Research and Innovation (RRI) practices in industry:

Providing the right incentives." In: *Sustainability* 9.10, p. 1759 (cit. on pp. 4, 18, 19, 22, 27).

Hajare, Damini (2018). *Introducing Magic Leap with Unity3D*. URL: https://www.yudiz.com/introducing-magic-leap-with-unity3d/ (visited on 12/10/2018) (cit. on p. 51).

Halliday, J. and J. Garside (2011). *Rioting leads to Cameron call for social media clampdown*. URL: https://www.theguardian.com/uk/2011/aug/11/cameron-call-social-media-clampdown (visited on 06/10/2018) (cit. on p. 4).

Hellström, Tomas (2003). "Systemic innovation and risk: technology assessment and the challenge of responsible innovation." In: *Technology in Society* 25.3, pp. 369–384 (cit. on p. 13).

Hoppe, Adrian H. et al. (2018). "Multi-user Collaboration on Complex Data in Virtual and Augmented Reality." In: *HCI International 2018 – Posters' Extended Abstracts*. Ed. by Constantine Stephanidis. Cham: Springer International Publishing, pp. 258–265. ISBN: 978-3-319-92279-9 (cit. on pp. 45, 46, 57).

Horizon2020 (2014). *Horizon 2020*. URL: https://ec.europa.eu/programmes/horizon2020/en/ (visited on 08/01/2018) (cit. on p. 14).

IEEE (1963). *IEEE Code of Ethics*. URL: https://www.ieee.org/about/corporate/governance/p7-8.html (visited on 06/01/2018) (cit. on pp. 10, 12).

IEEE (2018). *Ethics and Compliance*. URL: https://www.ieee.org/about/compliance.html (visited on 07/10/2018) (cit. on p. 10).

Jirotka, Marina et al. (2017). "Responsible research and innovation in the digital age." In: *Communications of the ACM* 60.5, pp. 62–68 (cit. on pp. 3, 5, 8, 14, 17, 24, 25, 27, 32, 33).

Johansen, Robert (1988). *GroupWare: Computer Support for Business Teams*. New York, NY, USA: The Free Press. ISBN: 0029164915 (cit. on pp. 38, 39, 41, 42).

Johansen, Robert (Jan. 1991). "Teams for tomorrow (groupware)." In: *Proceedings of the Twenty-Fourth Annual Hawaii International Conference on System Sciences*. Vol. iii, 521–534 vol.3. DOI: 10.1109/HICSS.1991.184183 (cit. on pp. 38, 39).

Katiyar, Anuroop, Karan Kalra, and Chetan Garg (2015). "Marker based augmented reality." In: *Advances in Computer Science and Information Technology (ACSIT)* 2.5, pp. 441–445 (cit. on pp. 52, 53).

Khairnar, Khushal et al. (2015). "Furniture Layout Application Based on Marker Detection and Using Augmented Reality." In: *International Research Journal of Engineering and Technology* 2.7, pp. 540–544 (cit. on p. 58).

Khronos (2018). *Runtime 3D Asset Delivery*. URL: https://www.khronos.org/gltf/ (visited on 11/11/2018) (cit. on pp. 80, 81).

Kim, Sung Lae et al. (2014). "Using Unity 3D to facilitate mobile augmented reality game development." In: *Internet of Things (WF-IoT), 2014 IEEE World Forum on*. IEEE, pp. 21–26 (cit. on p. 56).

Kim, Young-geun and Won-jung Kim (2014). "Implementation of augmented reality system for smartphone advertisements." In: *international journal of multimedia and ubiquitous engineering* 9.2, pp. 385–392 (cit. on pp. 51, 52).

Kiosk-Industry (2017). *NIKE USES AR AUGMENTED REALITY IN PARIS RETAIL*. URL: https://kioskindustry.org/nike-uses-ar-augmented-reality-in-paris-retail/ (visited on 09/20/2018) (cit. on p. 54).

Kraakman, Nick (2018). *The Best 3D Model File Format for your AR Applications*. URL: https://headjack.io/blog/best-3d-model-file-format-ar-applications/ (visited on 10/29/2018) (cit. on p. 81).

Krevelen, DWF Van and Ronald Poelman (2010). "A survey of augmented reality technologies, applications and limitations." In: *International journal of virtual reality* 9.2, p. 1 (cit. on pp. 54, 59).

Le, James (2018). *Snapchat's Filters: How computer vision recognizes your face*. URL: https://medium.com/cracking-the-data-science-interview/snapchats-filters-how-computer-vision-recognizes-your-face-9907d6904b91 (visited on 11/09/2018) (cit. on p. 53).

Lee, Taehee and Tobias Hollerer (2007). "Handy AR: Markerless inspection of augmented reality objects using fingertip tracking." In: *Wearable Computers, 2007 11th IEEE International Symposium on*. IEEE, pp. 83–90 (cit. on p. 50).

Liebert, Wolfgang and Jan C. Schmidt (June 2010). "Collingridge's dilemma and technoscience." In: *Poiesis & Praxis* 7.1, pp. 55–71. ISSN: 1615-6617. DOI: 10.1007/s10202-010-0078-2. URL: https://doi.org/10.1007/s10202-010-0078-2 (cit. on p. 20).

Mann, Steve et al. (2018). *All Reality: Values, taxonomy, and continuum, for Virtual, Augmented, eXtended/MiXed (X), Mediated (X, Y), and Multimediated Reality/Intelligence* (cit. on p. 50).

Martinuzzi, Andre et al. (Mar. 2018). "Responsible Research and Innovation in Industry—Challenges, Insights and Perspectives." In: *Sustainability* 10. DOI: 10.3390/su10030702 (cit. on pp. 18, 19).

Melnick, Kyle (2018). *This AR X-Ray Could Revolutionize Modern Medicine*. URL: https://vrscout.com/news/ar-x-ray-modern-medicine/ (visited on 08/27/2018) (cit. on p. 47).

Milgram, Paul and Fumio Kishino (Dec. 1994). "A Taxonomy of Mixed Reality Visual Displays." In: vol. E77-D, no. 12, pp. 1321–1329 (cit. on p. 50).

Nee, Andrew YC et al. (2012). "Augmented reality applications in design and manufacturing." In: *CIRP Annals-manufacturing technology* 61.2, pp. 657–679 (cit. on pp. 54, 59, 60).

NNI (2004). *The National Nanotechnology Initiative Strategic Plan*. URL: https://www.nano.gov/sites/default/files/pub_resource/nni_strategic_plan_2004.pdf (visited on 07/17/2018) (cit. on p. 13).

Northof41 (2018). *What really is the difference between AR / MR / VR / XR ?* URL: https://medium.com/@northof41/what-really-is-the-difference-between-ar-mr-vr-xr-35bed1da1a4e (visited on 11/10/2018) (cit. on p. 50).

Olson, Gary M. and Judith S. Olson (2008). "Computer-Supported Cooperative Work." In: *Handbook of Applied Cognition, Second Edition*, pp. 497–526 (cit. on pp. 37, 38, 40).

Orbit (2018). *Area 4P Framework*. URL: https://www.orbit-rri.org/about/area-4p-framework/ (visited on 08/17/2018) (cit. on pp. 32, 34).

Osterwalder, A. et al. (2014). *Value Proposition Design: How to Create Products and Services Customers Want*. Business planning. Wiley. ISBN: 9781118968055 (cit. on p. 68).

Owen, Richard, Phil Macnaghten, and Jack Stilgoe (2012). "Responsible research and innovation: From science in society to science for society, with society." In: *Science and public policy* 39.6, pp. 751–760 (cit. on pp. 3, 14, 15, 17).

Paladini, Marco (2018). *3 different types or AR explained: marker-based, markerless & location*. URL: https://www.blippar.com/blog/2018/08/14/marker-based-markerless-or-location-based-ar-different-types-of-ar (visited on 11/10/2018) (cit. on p. 52).

Poly, Google (2018). *Poly - Explore the world of 3D*. URL: https://poly.google.com/ (visited on 11/29/2018) (cit. on pp. 81, 82).

Purcell, Michelle W (2014). "On The Study of Open Source Software to Inform the Design of CSCW in Global Software Development." In: (cit. on pp. 41, 42).

Quora (2018). *The Difference Between Virtual Reality, Augmented Reality And Mixed Reality*. URL: https://www.forbes.com/sites/quora/2018/02/02/the-difference-between-virtual-reality-augmented-reality-and-mixed-reality/#5b455c692d07 (visited on 11/09/2018) (cit. on p. 50).

RRI-Plattform-Österreich (2016). *RRI in Österreich: Positionspapier: Verantwortungsbewusste Forschung und Innovation*. URL: https://www.zsi.at/de/object/publication/3952 (visited on 07/18/2018) (cit. on pp. 23, 24).

RRI-Tools (2015). *RRI Tools*. URL: https://www.rri-tools.eu/ (visited on 07/20/2018) (cit. on p. 31).

Schomberg, Rene Von (2013). "A vision of responsible innovation." In: (cit. on pp. 8, 9, 14–16, 21, 27).

SharingScience (2017). *Path to engagement*. URL: https://sharingscience.agu.org/engagement/ (visited on 08/15/2018) (cit. on pp. 35, 114).

Sheehan, Alexandra (2018). *How These Retailers Use Augmented Reality to Enhance the Customer Experience*. URL: https://www.shopify.com/retail/how-these-retailers-are-using-augmented-reality-to-enhance-the-customer-experience (visited on 09/14/2018) (cit. on p. 55).

Sketchfab (2018). *Sketchfab*. URL: https://sketchfab.com/ (visited on 10/29/2018) (cit. on p. 81).

Sony (2018). *Echte 4K Schönheit für jedes Bild*. URL: https://www.sony.at/electronics/4k-resolution-4k-upscaling-fernseher (visited on 11/10/2018) (cit. on p. 50).

Spiekermann, Sarah (2015). *Ethical IT innovation: A value-based system design approach*. CRC Press (cit. on pp. 5–8).

Stahl, Bernd, Grace Eden, and Marina Jirotka (2013). "Responsible research and innovation in information and communication technology: Identifying and engaging with the ethical implications of ICTs." In: *Responsible innovation*, pp. 199–218 (cit. on pp. 14–16, 20, 21, 25–27, 32).

Stahl, Bernd, Grace Eden, Marina Jirotka, and Mark Coeckelbergh (2014). "From computer ethics to responsible research and innovation in ICT: The transition of reference discourses informing ethics-related research in information systems." In: *Information & Management* 51.6, pp. 810–818 (cit. on pp. 5, 6, 8).

Stilgoe, Jack, Richard Owen, and Phil Macnaghten (2013). "Developing a framework for responsible innovation." In: *Research Policy* 42.9, pp. 1568–1580 (cit. on pp. 21, 27–30).

Szalavári, Z. et al. (Mar. 1998). ""Studierstube": An environment for collaboration in augmented reality." In: *Virtual Reality* 3.1, pp. 37–48. ISSN: 1434-9957. DOI: 10.1007/BF01409796. URL: https://doi.org/10.1007/BF01409796 (cit. on pp. 45, 46, 57).

ThinkMobiles (2018). *Best AR SDK for development for iOS and Android in 2018*. URL: https://thinkmobiles.com/blog/best-ar-sdk-review/ (visited on 11/11/2018) (cit. on pp. 56, 57).

Toolkit, RRI (2018). *Tool: ACM- Code of Ethics and Professional conduct*. URL: https://www.rri-tools.eu/-/acm-code-of-ethics-and-professional-conduct (visited on 08/15/2018) (cit. on p. 32).

Uchiyama, Hideaki and Eric Marchand (2012). *Object Detection and Pose Tracking for Augmented Reality: Recent Approaches* (cit. on p. 53).

Unity (2018a). *Model Targets User Guide*. URL: https://library.vuforia.com/articles/Solution/model-targets-user-guide.html (visited on 11/10/2018) (cit. on p. 53).

Unity (2018b). *Unity Manual - Model file formats*. URL: https://docs.unity3d.com/560/Documentation/Manual/3D-formats.html (visited on 11/26/2018) (cit. on pp. 80, 84, 85).

Vuforia (2018a). *Developer Portal*. URL: https://developer.vuforia.com/ (visited on 11/13/2018) (cit. on p. 77).

Vuforia (2018b). *Unlock the Value of Augmented Reality*. URL: https://www.vuforia.com/ (visited on 11/11/2018) (cit. on pp. 56, 75).

Wagner, Daniel et al. (2005). "Towards Massively Multi-user Augmented Reality on Handheld Devices." In: *Proceedings of the Third International Conference on Pervasive Computing*. PERVASIVE'05. Munich, Germany: Springer-Verlag, pp. 208–219. ISBN: 3540260080. DOI: 10.1007/11428572_13. URL: http://dx.doi.org/10.1007/11428572_13 (cit. on pp. 44, 58).

Walker, Tony Ross-Hellauer; Michela Vignoli; Elisabeth Lex; Hrvoje Lucic; Peter Kraker; Rainer Bachleitner; Viltė Banelytė; Edit Gorogh; Ilire Hasani- Mavriqi; Daniela Luzi; Roberta Ruggieri; Lucio Pisacane; Electra Sifacaki; Vilius Stanciauskas; Mappet (2018). *Ten steps to innovative dissemination*. URL: https://zenodo.org/record/1302349#.W3Vhi2UhnVq (visited on 08/15/2018) (cit. on pp. 35, 36, 113).

Wang, Jun, Arjen P De Vries, and Marcel JT Reinders (2006). "Unifying user-based and item-based collaborative filtering approaches by similarity fusion." In: *Proceedings of the 29th annual international ACM SIGIR conference on Research and development in information retrieval*. ACM, pp. 501–508 (cit. on p. 41).

Watts, Ian, Pierre Boulanger, and Greg Kawchuk (Nov. 2017). "ProjectDR: augmented reality system for displaying medical images directly onto a patient." In: pp. 1–2 (cit. on p. 47).

Webb, Helena et al. (2016). "Digital wildfires: Propagation, verification, regulation, and responsible innovation." In: *ACM Transactions on Information Systems (TOIS)* 34.3, p. 15 (cit. on pp. 4, 20).

Wikitude (2018). *Wikitude - Endless Ar Possibilities*. URL: https://www.wikitude.com/ (visited on 11/11/2018) (cit. on pp. 57, 74).

Wright, Ian (2017). *What Can Augmented Reality Do for Manufacturing*. URL: https://www.engineering.com/AdvancedManufacturing/ArticleID/14904/What-Can-Augmented-Reality-Do-for-Manufacturing.aspx (visited on 09/22/2018) (cit. on p. 60).

Xue, Jing (2017). *Top 10 AR furniture Apps Review in 2017*. URL: https://medium.com/inborn-experience/top-10-ar-furniture-apps-review-in-2017-c75c8f20775e (visited on 08/27/2018) (cit. on p. 58).

Appendix

Appendix A.

Appendix

A.1. 10 Steps to Innovative Dissemination

Figure A.1.: 10 Steps to Innovative Dissemination (Walker, 2018)

A.2. Paths to Engagement

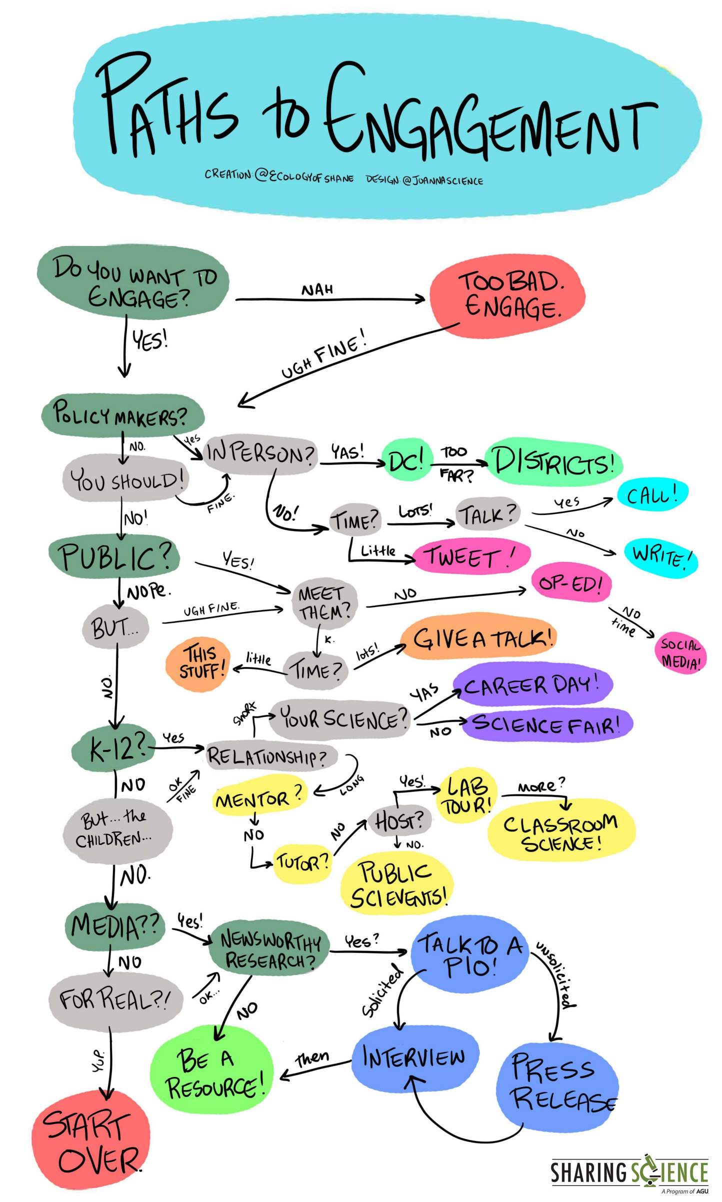

Figure A.2.: Path to Engagement (SharingScience, 2017)