Rathenau Instituut

Fake for real

Ethical and societal implications of augmented reality

Report

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Foreword

With augmented reality (AR) we are constructing a new environment, which is partly physical and partly virtual. We create digital versions of our streets, our living rooms and our bodies and add them to reality as virtual 'layers'. This enables us to virtually place furniture in our homes with a mobile phone, for example. The rise of this form of immersive technology heralds a new phase in the digital society. A phase in which the digital domain is no longer linked to a monitor, a mouse and a keyboard, but becomes an integral part of our perception of reality.

It reminds me of Lewis Carroll's famous story 'Alice through the Looking Glass', in which Alice climbs through a mirror and enters a new world. This world appears to be very similar to our own world, but turns out to be quite different. In the world through the looking glass, one can speak to chess pieces or flowers and adopt a new identity. The precise set of rules and behaviour that apply in this mirror world however are not entirely clear. As in Alice's mirror world, AR immerses us in a new environment – a world which seems familiar but is also somewhat different. In contrast to Alice's mirror world, this world has direct links to and consequences for our everyday environment. Can we really distinguish what is real from what is fake in this hybrid physical-virtual world? What impact does AR have on the design of our public space? And how can we ensure that immersive technology enriches our world rather than impoverishing it?

This report addresses such questions on the basis of desk research, in-depth interviews and artistic design-based research. Because our questions concern the future, imagination occupies a prominent place in this study. Together with our artist-in-residence, we created a number of scenarios and devised a game to spotlight the societal issues that are raised by AR. We observe that there is scarcely any public debate about our physical-virtual world. At present, the development of AR lies mainly in the hands of large technology companies. They design this mirror world according to their own commercial interests. However, there is a lot at stake with AR: it profoundly influences our perception of reality. It is therefore time for a broad public debate about AR in society. It is important for us all to think about the rules and social etiquette for a digitally augmented world. To initiate a wider debate, we present eleven rules for design of a responsible and liveable digitally augmented world.

This study falls under our research theme 'Digital society'. Under that heading we investigate new, immersive technologies that are changing how we interact with each other in the digital world: technologies in which we become submerged. Along this thematic line we also published a study on virtual reality (VR) entitled *Responsible VR: Protect consumers in virtual reality* and a study on voice technology.

Melanie Peters
Director, Rathenau Instituut

Summary

Our senses enable us to hear, see, feel and smell the physical reality that surrounds us. Augmented reality (AR) places digital layers over that physical reality to create ‘hybrid’ worlds, which are simultaneously physical and virtual. These hybrid worlds can be experienced with smartphones, headsets or smart glasses. They are operated not with a keyboard or a mouse, but through touch screens, voice, and by tracking the physical movements of our bodies and faces. In these worlds, gamers can hunt virtual monsters on the street, artists can install virtual works of art in the city and soldiers can receive tactical information directly in a combat situation.

In the last few years AR has become big business. Developments in the industry have led to innovations in a variety of sectors, including security, health care, architecture, marketing, education and training. By means of digital simulations, AR helps users to redesign work processes or to collaborate remotely. There are also successful consumer applications of AR, for example games such as *Pokémon GO* and social-media applications like Snapchat and TikTok (which use AR-filters). In the Netherlands alone, there are millions of users of these apps. Large American and Chinese technology companies including Google, Microsoft, Huawei and Bytedance employ thousands of people in their AR/VR activities and apply for thousands of patents for these technologies every year. A number of the largest internet technology companies are now developing their own AR-sets. In other words, such companies see AR as an important component of their future business model.

AR can be seen as a new phase in the information society, whereby the virtual domain spills over into the physical domain. AR changes how we see, hear and feel our environment – and consequently also how we can think about it and how we can act in it. The technology modifies our perception of reality. Users of AR no longer regard the online world as a separate domain, accessible via a laptop or a personal computer. With AR glasses, they look at the world ‘through the net’, as it were. At the same time, they experience the digital elements of that world in a three-dimensional and immersive manner. Users can control AR intuitively, for example through speech or with a wink or a hand gesture. The result is a blending of the physical and the virtual in the user’s experience.

Precisely because of the direct link between AR and the physical world, the technology also raises societal issues. In the first place, a lot of personal data is required to produce an AR environment. That raises issues of privacy, for example

in relation to the protection of personal data, data ownership and data security. Secondly, AR raises questions about the manipulation of perceptions and behaviour, since producers of AR applications are able to use devices and applications to manipulate what users see, hear and feel. Thirdly, the technology raises issues in relation to spatial planning. For example, is it a good idea to allow young people to search for virtual monsters close to busy roads, near railway lines, or at sacred sites? Is it permissible to place a virtual copy of the Chinese Wall beside the Dutch parliament?

The question we ask in this report is therefore:

How can AR be developed and applied in a socially responsible manner?

To answer that question, we explore how the technology works, which societal and ethical issues the technology raises and which role the government in particular can play in embedding AR in society in a socially responsible manner. We apply various research methods for our study. We sketch the current situation with AR in the Netherlands on the basis of interviews with designers, users and other stakeholders. In the process, we consider its use in professional practice (in neurosurgery, construction and logistics, for instance) and in entertainment applications. Our review of societal issues is derived from an analysis of relevant scientific literature. And because this study looks to the future, we also leave room for artistic imagination.

How does AR work?

AR can be seen as a new type of environment which differs fundamentally from both the physical and the virtual environment. The specific feature of AR is that the physical and virtual environments blend into one another to create a hybrid physical-virtual environment. Users can experience that environment with a range of AR systems. These systems do two things. First, they create a hybrid environment by creating virtual elements and linking them to specific physical locations, objects or people. For instance, a face filter on Snapchat produces a mask of an animal that is directly linked to a real time, digital image of a person’s face. Second, AR systems function as an interface between the user and the hybrid environment, which means that the user can observe the hybrid environment by means of screens, audio devices or haptic equipment and can perform actions within it.

A wide variety of digital technologies are used in this process: biosensors, cameras, powerful processors, artificial intelligence, digital platforms and robotics. These technologies are used to collect, analyse and apply data about the user and his or her environment. In this way, the user is continuously monitored by an AR system.

The data that are generated are linked to pre-programmed information or information that the system finds in other databases, in profiles or on the internet. The virtual elements of the hybrid environment are constantly adapted to the user's changing circumstances, so that he or she can experience the AR world as 'natural'.

Eleven design rules for a hybrid world

At present there is scarcely any public debate about the hybrid world: how it should look and who should be involved in designing it. The development of AR technology is currently dominated by – mainly large – commercial technology companies. They design the hybrid world to serve their own, private interests. However, there is a lot at stake with AR: not only our perception of reality, but also the design of the physical environment – also for those who do not use AR. From the perspective of the public interest, it is irresponsible to leave the necessary decisions entirely to the market. It is high time for a broad political and public debate about the embedding of AR in society.

To initiate such a debate, this report formulates eleven design rules for socially responsible AR. These rules are inspired by the societal and ethical issues that we see emerging in relation to the use of AR. On the basis of our research, we distinguish between three types of issues: data issues, perception-control or manipulation issues and spatial planning issues. Below, we mention a number of specific societal and ethical issues in each of those categories, accompanied by a number of design rules and actions the government should take in relation to them. The recommended actions are printed in italics.

The first design rule transcends the individual issues and emphasises the importance of collaboration between all stakeholders in aiming for responsible AR: companies, citizens, knowledge institutes and civil-society organisations. The government should be at the forefront of the search for a liveable hybrid world.

Design rule 1. Make a joint effort to create responsible AR

Data issues, design rules and required actions

AR systems use personal data. This means that they gather information about the location of the AR user, but also about that person's physical movements, gestures, facial features and behaviour. AR systems also register a variety of data about the environment, not only the location and characteristics of objects, but also data about other AR-users, and even non-users. This is often intimate information from which unique individuals can be identified. The use of AR devices, for example smart glasses with cameras, can therefore threaten the anonymity of people in public and private spaces. Moreover, applications can share the assembled data with third parties without the user's knowledge.

Besides privacy issues, AR also raises various ownership issues. AR applications can lead to infringements of property rights, or to destruction of private or public property by encouraging people to go to locations that they would not otherwise visit. It is also possible to digitally modify physical property with AR, which raises the question whether virtual spray painting, for example of another person's house or a public building, is permissible. Another question is whether users have exclusive rights to their own observation or movement profile. Data about facial and eye movements can provide insights into what users observe. These data are useful for AR companies in helping them to create hybrid worlds, but they are also lucrative, because the data can be used to profile and influence users for commercial purposes.

These data issues call for sharper definitions and explicit legal frameworks. How should ownership be defined and regulated in a hybrid environment? Should companies be allowed to process users' biometric and other 'intimate' data, and if so, how?

These questions lead to the three following design rules and required actions:

Design rule 2. Guarantee the privacy of AR users

Design rule 3. Guarantee the anonymity and privacy of non-users

***Required action**: Until rules have been adopted by the European Commission, the Dutch government should impose a moratorium on the use of AR applications in the public space by which citizens can be identified through biometrics.*

Design rule 4. Clarify issues of both physical and virtual ownership in the hybrid world

***Required action**: The Ministry of Justice and Security should clarify the legal frameworks concerning ownership of virtual objects, particularly in relation to the ownership of humans, including their body.*

Manipulation issues, design rules and required actions

An AR device can be seen as a digital prosthesis that digitally modifies our perception of reality. In doing so it influences what we see, hear and feel, and possibly also what we think and do. AR can therefore affect the physical and mental well-being of its users. The technology is developing rapidly and provides increasingly powerful immersive experiences, making it more and more difficult for users to make the distinction between virtual and physical, and between fake and real. Accordingly, parties that develop AR-systems, -platforms or -content are able to determine what a user experiences in steadily more profound ways. This can be useful, in the context of therapies or learning for example, but can also weaken the information position of citizens or even lead to deception.

AR can increase people's cognitive capacities in many ways. On the work floor the technology can be used to quickly teach employees new skills. However, there is also a potential downside. If AR technology determines precisely when an employee has to perform a particular action, human labour could also be degraded to robotic work. In the entertainment domain, apps such as Snapchat can provide enjoyment, but they also encourage users to create an ideal digital image of themselves. There are therefore concerns that frequent use of AR not only creates the risk of addiction, but can also distort a person's self-image or even lead to forms of body dysmorphic disorder (BDD).

In view of these manipulation issues, there is a need for more scientific reflection and public debate on the social significance of AR as a technology that stands between us and reality.

Those issues lead to the following four design rules and necessary actions:

Design rule 5. Protect the mental and physical health of AR users

Necessary action: *The Ministry of Health, Welfare and Sport should promote research and public debate on the health effects of AR. The Ministry of Education, Culture and Science should ensure that attitudes towards AR are covered in the policy on digital literacy.*

Design rule 6. Strengthen human capacities in a fair and dignified manner

Design rule 7. Protect people's cognitive autonomy

Necessary action: *The government should promote research and debate on social standards and values (social etiquette) in the hybrid world.*

Design rule 8. Ensure fair power relations in the hybrid world

Required action: *The Ministry of Economic Affairs should clarify how the government will guarantee fair relations between companies and between companies and AR users in the AR domain.*

Spatial planning issues, design rules and required actions

Because AR links the digital world directly to the physical environment, it also raises issues in relation to spatial planning. AR offers possibilities to digitally redesign the physical environment. That has consequences not only in the hybrid environment as experienced by the user, but also in the physical space and for others present in it. For example, the introduction of *Pokémon GO* created a situation in which thousands of players of the game were drawn to seaside resort Kijkduin in The Hague, where they caused various forms of nuisance for local residents and damage to the nature.

The digital world with its cookies and trackers is now penetrating into spaces and physical environments that used to be entirely analogue. The digital domain is ‘colonising’ the physical world, as it were, which can lead to further commercialisation – also of public spaces such as nature reserves, beaches or town squares. This could impair the public character and communal nature of those locations.

Because AR has far-reaching consequences for the use of our physical space, it is important for the government to explore how the hybrid world can be designed in a socially responsible manner and what rules are needed to accomplish that.

These issues lead to the following three design rules and necessary actions:

Design rule 9. Give citizens control over their physical-virtual identity
Necessary action: *The Ministry of Justice and Security should clarify what the right to physical integrity means in the context of AR.*

Design rule 10. Create public spaces in the hybrid world
Necessary action: *The government should investigate how the public character of the hybrid public space can be guaranteed in the long term.*

Design rule 11. Design the hybrid environment in a socially responsible manner

Necessary action: *The government should explore how the hybrid environment can be designed in a socially responsible manner.*

Contents

1 Blending the physical and the virtual

1.1 Introduction

We experience physical reality with our senses. We see the blue sky, hear the sea and feel the wind in our hair. With augmented reality (AR), virtual elements can be added to that reality. This creates a 'hybrid reality', which has both physical and virtual elements. With smartphones, AR headsets or smart glasses, AR users can experience this digitally modified reality and perform actions in it. This makes it possible, for example, to hunt for virtual monsters at the railway station, to provide soldiers with tactical information in combat situations, to place a virtual face mask on a person's face or to design machines (see figure 1.1). This way, AR systems can digitally influence people's cognitive and sensory capacities in many ways.

Figure 1.1 Use of AR by engineers

Source: Microsoft

Although AR technology is still evolving, AR is certainly not science fiction any longer. The first professional AR applications were introduced in the early 1990s by the American air force (Rosenberg 1992) and at plane manufacturer Boeing (Caudell & Mizell 1992). Nowadays, armies around the world use AR headsets for digital simulations, training and remote collaboration, for example. The American army has already ordered more than a hundred thousand units of the HoloLens, the AR headset that Microsoft launched in 2016 (Brustein 2018). In the last decade, the use of headsets and smart glasses has also taken off in other professions. Surgeons experiment with visualisations in AR, architecture firms use AR systems to create three-dimensional designs of buildings, and operators of distribution centres hope that headsets with AR-instructions will enable their employees to work more efficiently.

There are also numerous AR applications for consumers. Many will recall Google Glass. The bèta version of these smart glasses was launched in 2014, but the product was taken off the market again in 2015 because of privacy objections. *Pokémon GO*, a game app for the mobile telephone, was more successful. In 2016, the game broke all download records when it was downloaded 50 million times within nineteen days (Nelson 2016). *Pokémon GO* uses AR and GPS to position virtual creatures, called Pokémon, in the public space. Players can find and catch these creatures with the camera on their smartphone. Well-known social-media applications such as Instagram (5.6 million users in the Netherlands), Snapchat (2.7 million users) and TikTok (400,000 users) also have AR options with which photos and films can be modified with virtual layers in real time (Oosterveer 2020). Another example is the popular app IKEA Place, with which users can arrange virtual furniture in their home on a tablet or smartphone. Finally, smart earbuds are another popular application of AR. One refers in that context to augmented hearing, because the earbuds can suppress or amplify sounds in the environment or add other audio signals – such as music – to them.

AR developers promise us exciting new experiences and numerous possibilities to design and experience our home, our street and our office in a novel way. The rise of the technology also raises ethical and societal issues. For example, how do we feel about companies using AR games to tempt (often young) players to buy their products? What do we think of the fact that AR applications with their smart cameras can recognise and register the faces and the behaviour of unsuspecting passers-by? And what is done with all the intimate data that is collected about users and non-users?

In this chapter we start off by giving a definition of AR. On the basis of this definition, we argue that the technology heralds a new phase in the information society, a phase in which the digital domain is colonising our physical environment and digital technology can change what we see, hear and feel. We then discuss the conceptual framework we developed to explore the social significance of AR. Finally, we present the research questions that we address in this report and describe the structure of the report.

1.2 AR as hybrid physical-virtual environment

AR is best understood as a new type of environment that is fundamentally different from both the physical and the virtual environment. We experience the *physical environment* directly with our senses, without digital tools. The physical environment is determined by a particular place and it changes over time. Social standards and rules apply in the physical environment. There are specific rules of behaviour in a theatre, just as there are on the village square.

In contrast to the physical environment, there is the entirely computer-generated *virtual environment*. The virtual environment is created with digital technology and can only be experienced with digital technology. Experiencing that environment requires the use of a special system – a virtual reality system (or VR system) – which submerges the user in a simulated, virtual environment. Virtual reality is largely separate from the existing physical context and also has a different social context. Because the virtual reality is entirely digitised, Munnik (2013, pp. 342-344). describes it as a placeless and contextless reality.

The main feature of AR is that the physical and virtual environments blend together to create a new type of *hybrid environment,* which is both physical and virtual (see figure 1.2). In experiencing a hybrid environment, the user is physically or bodily present in the environment and is aware of it, but is also able to experience virtual elements. Thus, in contrast to the placeless VR, AR is an environment in which people are (also) physically present and which is always connected to a particular place, time and social context. The physical and social context in which AR is applied is therefore a crucial factor in studying the societal and ethical aspects of AR.

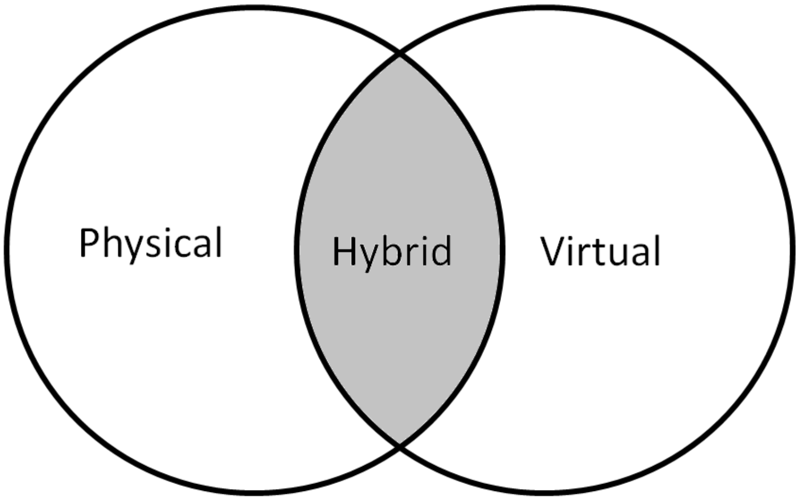

Figure 1.2 Hybrid physical-virtual environments consist of a combination of physical and virtual elements.

Source: Rathenau Instituut

AR systems

AR can only be experienced with AR systems, such as headsets, projectors or smart phones. These systems do two things. First, they create a hybrid environment on the basis of a variety of data. Second, they function as an interface between the user and the hybrid environment, enabling the user to observe the AR environment (by means of image, audio and sensors) and to perform actions within it.

AR systems create a hybrid environment by producing virtual elements and coupling them to specific physical locations, objects or persons. An example is a virtual menu linked to the door of a particular restaurant. That information is laid over the physical environment. Mann (2013) refers in that context to virtual 'layers' and argues that AR involves 'superimposing' different types of virtual layers over the user's physical environment and thus digitally expanding or 'augmenting' it. The virtual layers generally add something to the physical or material environment, but they can also remove something from it by modifying or hiding components of the environment. The result is referred to as diminished reality (see Kunert et al. 2019; Kotsios 2015). A software programmer in Silicon Valley, for example, created a distasteful AR algorithm with which homeless people could be filtered out of the streetscape in San Francisco (Halting Problem 2016).

The AR system also enables the user to experience the aforementioned algorithmically constructed hybrid environment. There are various devices for this, ranging from smartphones and tablets to AR headsets and smart glasses. Media scientist Lev Manovich describes AR as a new interface paradigm ‘involving the laying of dynamic and context-specific information over the visual field of a user’ (2006, p. 222). Bo Brinkman refers to it as a ‘technology for presenting virtual objects, which […] are linked to the real world, to an individual’s senses’ (2014, p. 151). This can involve sight (where it is a visual experience), but also other senses such as hearing (an auditive experience) or touch (a haptic experience).

In AR systems a cluster of digital technologies work together: biosensors (such as facial and behaviour recognition cameras), powerful processors, artificial intelligence (AI), digital platforms, persuasive technology, VR and robotics. These technologies are used to collect, analyse and apply data. The AR system continuously monitors the user and his or her environment. In the process, information about this user and environment is linked to pre-programmed information, or information found by the system in other databases and profiles or on the internet. On the basis of the analysis of this data, the virtual elements of the hybrid environment are continually adapted to the user’s changing circumstances, so that he or she can experience a ‘fluid’ hybrid environment. In other words, more than anything else an AR system is a digital data machine: a technological system that collects, analyses and applies data.

To sum up, we can say that AR systems are **digital data machines**, which collect, analyse and apply data and create a **hybrid physical-virtual environment**. At the same time, they are also **interface systems**, which give the user **sensory access** to a hybrid environment and allow this person to perform actions in it. The hybrid physical-virtual environment constructed by AR is bound to a **place, time and social context** and is made up of physical elements and **virtual layers**. Many virtual layers are **visual** in nature (they are presented on a screen in the user’s field of view), but can also address other senses if they provide **audio feedback** (via a headset, for example) or **haptic input** (via technology that encourages physical contact and so activates the sense of touch). AR systems can digitally alter people’s cognitive and sensual capacities in various ways and thus **digitally modify the perception of reality**.

1.3 Digitisation of the perception of the world

The digitisation of our perception of reality by means of immersive technologies like AR, heralds a new phase in the information society. With the rise of PCs in the

1970s, the computer assumed an increasingly important role in various domains in society, including the home (Bogaard et al. 2008). In the 1990s, the PC became part of the global communication network, the World Wide Web. Vast numbers of people started using the internet at home. The arrival of laptops, and particularly smartphones, made computing mobile and brought it into the public space (Hof et al. 2011). More and more new digital devices also started appearing in the public space, such as gates that could only be opened with digital passes, smart cars and cameras to monitor humans and vehicles. Accordingly, the internet increasingly became a network of devices that surrounds us wherever we are. The public space became an Internet of Things.

In *Check in / check out. The public space as an Internet of Things,* this new phase in the information society was described with the slogan: ‘We go from being *on* the net to being *in* the net’ (Hof & Est 2011, p. 16). At that time, the notion of ‘*in* the net’ referred to the trend whereby people were increasingly surrounded by a network of computers, both visible and invisible. Those computers made it possible for everyone to surf ‘*on* the net’ and connect with cyberspace wherever and whenever they wanted. AR devices contribute to the digitisation of public and private space. As a new type of interface, AR, and particularly portable AR glasses, are creating a new phenomenon. While we normally look *at* cyberspace on our smartphones, we look *through* an AR device at a hybrid mix of physical and virtual reality. With AR, we not only go *into* the net, but see, hear and feel *through* the net.

Consequently, AR glasses digitise the physical world in which we live in a very intrusive manner. We argued above that AR technology digitally maps the physical world and the human environment. This makes it primarily an intimate (Rathenau Instituut 2014b) surveillance technology (Zuboff 2019). Secondly, AR superimposes virtual layers onto the physical world, and thus the technology creates a hybrid, physical-virtual world. In this way, AR systems are causing a further digital colonisation of the world we live in. Thirdly, the technology allows AR users to perform actions with and in the hybrid world. In the process, users subject their sensory experiences of reality to digital filters. In other words, AR essentially involves the digitisation of human perception of the (physical) world.

American and Asian tech giants like Samsung, Huawei, Facebook, Google, Microsoft and Magic Leap (which has received major financial injections from Google and Alibaba) are currently investing billions in the AR industry. Facebook, for example, now has more than 3,000 employees working on AR/VR. Large technology companies applied for hundreds of AR-related patents between 2002 and 2017. Microsoft led the way with no fewer than 745 applications (Ghaffary & Molla 2020). In 2019, more than 7,000 inventions relating to AR/VR were patented worldwide. In other words, tech companies see AR – and the possibilities that this technology offers for mapping and manipulation of human behaviour and perception – as an important element of their future business model.

1.4 The social significance of AR

The combination of the rise of numerous professional applications of AR in the public and private sectors, the commercial breakthrough of various consumer applications and the investments that large tech companies are making in developing AR, and the socially radical character of AR, means that there is an urgent need to clarify the social significance of AR.

Above, we described AR as a data machine, but also as a machine that influences the perception of reality and a machine that shapes hybrid spaces. On that basis, we distinguish three types of societal issues: data issues, perception-control or manipulation issues and spatial planning issues. We briefly elaborate on those issues below. Since AR involves hybrid, physical-virtual environments, we assume that it can make a fundamental difference *where* – in which physical environment – AR is used. We therefore make a further distinction between three types of space: the public space, the private space and the personal space.

Societal issues
In the first place, AR raises various data-related issues, such as questions concerning the protection of personal data, data ownership and data security. AR is a digital information and communication technology and functions as a data machine. To build a hybrid environment, AR systems gather a lot of information about users and non-users. AR systems store and process the data, and often also share them with other systems. The data is used to add virtual layers to the physical environment, with the result that the perception of reality is influenced.

That latter aspect gives rise to a second category of issues relating to the manipulation of perceptions and behaviour. Producers of AR applications are able to control and steer what users see, hear and feel with their applications. In this way, AR applications also control and influence what their users know and think and how they act (or can act) in the world.

Thirdly, we distinguish issues relating to spatial planning. The use of AR applications such as *Pokémon GO* has an impact on the social and cultural use of the physical space and raises questions about the social structure of that space. The question here is how the hybrid environment is designed, by whom, and for what purpose, but also what consequences the use of AR has for the physical environment. Is it a good idea to use a train station as a location for playing a game? Should it be permitted to place a virtual copy of the Chinese Wall beside the Dutch parliament buildings? And is a user of AR free to spray virtual graffiti on my house or alter the colour of my skin?

The location-specific application of AR

The precise social significance of AR depends heavily on the space that is ‘hybridised’, or partially virtualised, by AR. This report considers the impact of AR on three types of space: personal, private and public space. These domains can overlap and the boundaries between them are not always clear. Nevertheless, it is important to distinguish between them in this study because different social standards and cultural and legal rules apply in each of them.

People regard their personal space as their territory (Dijk 2014). This means they consider themselves to be the owner of that space and wish to have control over it. The physical extent of that personal space depends on the context. How far people allow others to enter their personal space also depends on their mutual relationship. Personal space is therefore not only a physical space, but also a ‘mental’ space: a space where people express their emotions and shape their identity (Katell et al. 2019, p. 298). In the context of the application of AR in the personal space, therefore, there are also issues relating to a person’s body and mind, the design of our hybrid identity and the control of our data, behaviour or environment by other persons or organisations.

Private space is space that is not accessible to everyone, where private life take place. Examples are the bedroom or the home, but also a workplace such as an office, an operating theatre or a shipyard. Issues that arise in relation to the use of AR in private space concern matters such as the automation of human processes at work or the invasion of privacy. For example, Google Glass, with its built-in, almost invisible camera, caused uproar over privacy in 2013, with the result that wearing the smart glasses was banned in various places, for example in some cafés.

Finally, public space is a space that is usually open and accessible to everyone (VROM Council 2009). Public life takes place to a large extent in the public space, which can be managed by the government or by private actors. AR in this domain raises issues relating to the design of the public space and friction between different sets of rules. The use of the *Pokémon GO* app in 2016, for example, attracted hordes of players to locations such as protected nature areas, graveyards and memorial sites including Hiroshima Peace Park. This caused considerable social friction (see chapter 3).

1.5 Research questions

AR is a surveillance technology that can profile users and as such, influence their perception. Accordingly, AR symbolises a new phase in the information society, whereby the digital domain colonises our physical environment and technology changes our perception of reality. It is therefore important to identify the social significance of AR in good time and to conduct a debate on the subject. The aim of this study is to illuminate the current situation with AR and initiate a discussion of how AR can be embedded in society in a socially responsible manner. We make recommendations for policymakers, researchers and developers, companies and users of AR, and citizens for arriving at socially desirable AR applications. Our central question is:

How can AR be developed and applied in a socially responsible manner?

We have broken that general question down into three specific questions:

1) How does AR work, what is the current situation with respect to the development and use of AR, and what are its prospects for the future?

2) Which practical societal and ethical issues arise now or are expected to emerge in the coming years in relation to AR?

3) Which conditions should apply for socially responsible applications of AR?

We have employed various methods to answer these questions. In addition to desk research and interviews, we use artistic design-based research. The subject matter of this study is future-oriented. That leaves room for explicit use of the (artistic) imagination. Roos Groothuizen, artist-in-residence at the Rathenau Instituut, was a member of the project team. Together with programmer Allan Lyon, she devised *Mirror Worlds*, a game designed to highlight the societal and ethical issues ensuing from the use of AR in the public space. Roos Groothuizen also formulated a number of visual future scenarios that provide insight into societal and ethical issues relating to AR, as well as potential technological and political solutions for them. The scenarios are presented in an Intermezzo between chapters 3 and 4.

This report on AR is part of a broader programme of the Rathenau Instituut devoted to immersive technologies. That heading covers research into virtual reality, augmented reality and voice-based virtual assistants. The study covering VR was published earlier under the title *Responsible VR: Protect consumers in virtual reality* (Rathenau Instituut, 2019). The studies build on previous reports published by the Rathenau Instituut under its research theme ‘Digital society’ (cf. Rathenau Instituut 2017b, 2018b).

1.6 Reader's guide

To understand the social significance of AR, it is essential to properly understand how AR systems work. In chapter 2 we describe AR as a digital data machine, a system that collects, analyses and processes data. We also explain how AR as an interface influences the user's perception, what AR devices there are to experience hybrid worlds, and some scenarios that already exist for the future of AR.

Chapter 3 discusses current uses of AR in the Netherlands, both by professionals and consumers. While some of the applications discussed are still being developed, others are already on the market. The chapter further highlights the technical, societal and ethical issues that arise in practice in relation to AR. We review six different uses: AR in neurosurgery, AR in the construction of the Boekelo bridge, AR for vision picking in distribution centres, AR for deck marking in the maritime sector, and AR in playing the *Pokémon GO* game in The Hague. The last practice we discuss is one we designed ourselves as part of the study. In that example, a group of students played the game *Mirror Worlds* at a public location.

Chapter 4 elaborates on the ethical and societal issues that are mentioned in the scientific literature, which in addition to reflecting on the current practice of AR also considers issues that could emerge in relation to AR in the coming years.

Chapter 5 sets out the design rules that socially responsible applications of AR should meet. The rules are accompanied by recommendations for policymakers, researchers, developers, companies and citizens for devising socially responsible AR applications.

As already mentioned, we also present a number of illustrated scenarios that address the question of how we should deal with AR in the future (Intermezzo). The scenarios were developed by Roos Groothuizen, in collaboration with the authors of the report, and are explained in the Intermezzo.

2 How AR works

2.1 Introduction

As mentioned, the issues raised by AR technology fall into three categories, respectively concerning data, manipulation and spatial planning. These issues relate to the technological features and possibilities of AR systems. For example, large volumes of data about the user and his or her environment is required in order to create hybrid environments. This is particularly significant in light of the fact that other people than the user are also part of such environments. As a result, the mass collection and processing of data raises various privacy issues. Furthermore, AR-systems enable users to experience a hybrid environment, which means that what users hear, see and feel can be digitally manipulated. This leads to questions about freedom of choice and mental health. Chapters 3 and 4 discuss the societal issues raised by AR in detail. Given their connection with the workings of AR, we first explore this aspect in more depth in this chapter.

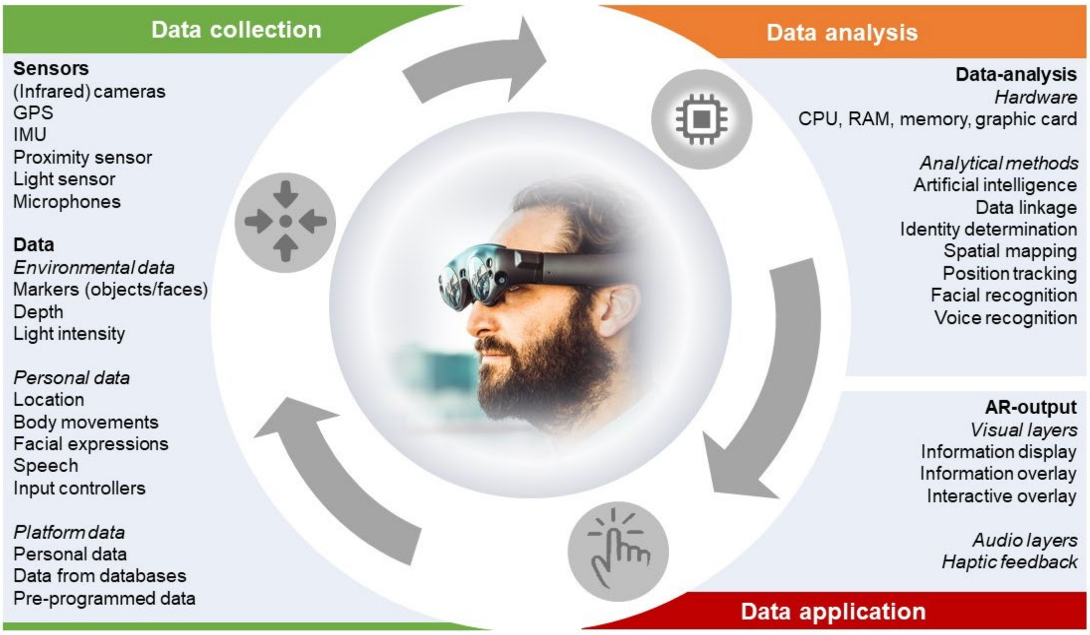

Figure 2.1 AR in the cybernetic loop

Source: Rathenau Instituut

An AR system runs on data – much like any other digital system. An AR system is a so-called cybernetic data machine, a system that simultaneously collects, analyses and applies data (figure 2.1). The data is used specifically to produce a hybrid, physical-virtual environment that can be experienced by users. A cluster of digital technologies is employed to accomplish this: sensors, various forms of data analysis (including artificial intelligence, or AI), platforms, persuasive technology and robotics. These technologies play a key role in the Internet of Things, which connects devices and humans. With the help of all these technologies, AR systems can produce a continuous interaction between the physical and virtual worlds.

This chapter describes how AR technology works on the basis of the cybernetic feedback loop and its three phases. We begin by describing which sensors collect which data (phase 1) and how this data is analysed (phase 2, described in section 2.2). This information is particularly important for identifying data-related issues. We then zoom in on the third phase of the cybernetic loop, the application of data (section 2.3), where we discuss how AR systems create a hybrid, physical-virtual environment and how users can experience this hybrid environment through various interfaces. We need this knowledge in order to properly frame issues relating to manipulation. Section 2.4 provides an overview of AR devices, each of which in its own way enables experiences of the hybrid environment. Next, we sketch a number of future scenarios for AR (section 2.5), which could determine the further development of AR systems. We conclude with a summary of our main findings (section 2.6).

2.2 Data collection and analysis

Data collection: types of data and sensors

AR systems consist of numerous sensors that collect large volumes of data. We make a distinction between environmental data, personal data and platform data.

Environmental data have to be gathered to map the physical environment, including people and objects, and to properly match virtual layers to it. A wide range of sensors are used for this purpose. Many of them are cameras that produce videos and photos, and can also perceive depth. Advanced AR headsets such as Microsoft's HoloLens have four cameras that register the environment and enable the recognition (in the analytical phase) of the user's physical movements. They also have two infrared cameras to monitor the user's eye movements. In addition, there is a so-called time-of-flight camera, which maps the environment and depth in real time by measuring light reflections (Li 2014). Depth can also be measured with markers in the physical space, such as QR codes. Light sensors can be used to adapt the light intensity in the virtual layers to that of the physical environment.

AR systems collect *personal data* to determine how the user relates to the hybrid environment in which he or she moves about. The user's location is usually established with GPS, a system that uses satellites in space to pinpoint the user's location on earth (Wing et al. 2005). GPS is often used in combination with a gyroscope, which measures the angle and position of the AR device, and an accelerometer, to determine the speed, movement and rotation of the device. If necessary, a magnetometer, which serves as a compass, helps with orientation. These three types of sensors together constitute the so-called Inertial Measurement Unit (IMU) and ensure that digital layers adapt smoothly and imperceptibly to the user's movements (Ahmad et al. 2013). This provides freedom of movement, which is also known as 'six degrees of freedom' (6DoF). To gather more data about the user and position him or her in the hybrid environment, the angle at which the user is viewing the environment can also be registered (Jiang 2004). For this purpose, both one's body and the head are monitored, and sometimes also one's eye movements or other facial movements (Renner & Pfeiffer 2017; Kitanovski & Izquierdo 2011).

Personal data can also play a role in the operation of AR. In addition to control buttons and controllers, AR applications frequently use data about hand gestures, facial expressions, hand movements, body motions and speech in order to control the hybrid environment (Funk et al. 2017; Chen et al. 2017; Jindal et al. 2018). Cameras also play an important role in this respect. For example, some cameras focus on the environment to track the user's hands, while others are concentrated on the user's face to monitor his or her eye movements (in many applications, the means by which they are operated).

Finally, AR systems use *platform data*. If AR technology is connected to the internet (via WiFi, for example), information from the web, from the application's developers or from existing databases can be used. These sources may include pre-programmed data, data about a user's search history, cookies, a user's digital data (from e-mail accounts or digital diaries, for example) and profiles of other users (Rauschnabel 2019; Hautala 2016; McCorskey 2018; Miller et al. 2020).

Data analysis: methods of analysis

Hardware and software are needed to process data. The hardware mainly consists of a CPU, RAM memory, a video card, a memory card and Bluetooth and/or a wireless data network (WiFi) with an internet connection (Tripathi et al. 2017). In some headsets, such as Microsoft's HoloLens, this technology is pre-installed on the AR device. In contrast, smart glasses such as Google Glass and Focals use a smartphone or computer connection (Nayak 2014). The data can be stored, combined and analysed on the AR device or in a cloud environment. Environmental data and personal data are normally analysed with AI methods, such as machine learning techniques. Examples of such methods include spatial mapping, position tracking, image recognition and voice recognition (Chen et al. 2019; Park et al. 2020).

With spatial mapping, a representation of the physical environment is produced, so that it can be combined with virtual elements. Points in the physical environment are collected and connected to each other using AI. This enables users of the IKEA Place app, for example, to produce a representation of a living room and place virtual objects, such as furniture, in this space (Pardes 2017).

Position tracking determines the user's position in the hybrid environment using GPS, IMU and camera data (Shea et al. 2017). Head, eye and hand tracking are specific forms of position tracking. With head tracking, the system calculates the movements of the user's head in order to adapt the appearance of virtual objects to their field of vision (Jiang 2004). Eye tracking uses data generated by cameras directed at the eyes, which can determine what a person is looking at from the orientation of their pupils (Meulen et al. 2017). With hand tracking, hand gestures are analysed to enable users to perform actions with virtual objects (Ungureanu et al. 2020).

Image recognition is sometimes also used to identify visual elements; here, methods are used for the automatic recognition of visual patterns. Sensor data, for example a photo, is linked to external databases and compared with thousands of other photos. An unknown object or person encountered in AR can then be quickly identified (Gammeter & Gassmann 2010).

Finally, some AR applications use voice recognition – likely familiar to most reader due to the increasing popularity of virtual assistants like Siri, Alexa or Google Assistant. Here, speech is recorded using a microphone and converted into text. This method is usually employed to operate functions such as a camera or the phone-calling function in an AR headset (Statt 2018).

2.3 Data application: creating and experiencing AR

AR uses data to create a hybrid physical-virtual environment that can be experienced by users. This section describes how hybrid environments are created and how users can experience an AR environment. AR can be understood as some sort of a digital prosthesis, which expands a person's cognitive and sensory capacities. This process is often referred to as 'human augmentation', or in other words: the interactive digital expansion of human capacities (cf. Raisamo et al. 2019). In this section, we describe how AR can augment the cognitive and sensory capacities of users. We conclude the section by explaining how users can become immersed in AR.

Virtual layers over the physical world

All the data that is assembled and analysed serves to produce virtual layers that are overlaid onto the physical environment. It is in this third phase of the feedback loop, then, that a hybrid environment is created.

Hybrid environments consist of virtual layers that can be fairly simple, but also more complex. *Information displays* are relatively simple digital layers that take the form of text, audio, still images or video. In this case, a layer is overlaid onto a representation of the physical environment, but not directly linked to it. One might think here of text messages, for instance, or the speed indicator that is projected onto the windscreen in cars equipped for this purpose. With *information overlays*, in contrast, the layer is linked to points in the physical environment. Consider here a virtual menu that appears when an AR app is pointed at a restaurant. With an *interactive overlay* the user can also perform actions with the virtual elements. In the AR game *The Walking Dead: Our World,* for example, players have to kill zombies in the street. And in *Dynamics 365 Guides,* the user can learn how to assemble a motorbike with visual instructions.

Besides visual layers, AR can also use audio or touch. In the case of touch, users receive haptic feedback which they experience as pressure or vibrations on their hands or bodies. Controllers, gloves or suits can be used for this purpose. Haptic functionality can enable gamers to ‘touch’ virtual monsters, but also allow people to physically connect with each other in a virtual environment (Jeon & Choi 2009).

Sound is produced with a headset, earbuds and speakers, or possibly smart glasses with ‘bone conduction’ functionality. In the latter case, vibrations transmitted via the skull create a (three-dimensional) audio experience (Ingraham 2013). A user of such functionality might for instance be able to hear hybrid monsters growling. The term ‘AR audio’ also applies in the case of smart earbuds, which digitally amplify or suppress sound from the physical environment or combine it with (virtual) sounds such as music. Some smart earbuds can be operated with voice commands (O’Kane 2016). The rapid rise of virtual assistants like Google Home illustrates how far voice-controlled interaction with machines has advanced. Like haptic feedback, audio functionality contributes to the immersivity of the experience: the extent to which the user feels immersed in the hybrid space (Eckel 2001).

AR as prosthesis

AR systems create hybrid environments but also function as an interface between the users and those environments. Accordingly, AR can serve as a digital prosthesis. Below, we describe three ways in which the cognitive and sensory experience of users can be enriched. In these three cases, AR performs an information function, a manipulation function or a communication function, respectively.

Information function

Some AR applications reflect the human need to make the physical environment readable or interpretable (Manovich 2006, Bolter et al. 2013, Graham 2017 and Uricchio 2019). Virtual layers can provide information about the immediate environment. The AR function of the navigation software *Google Maps* illustrates this function quite well (Paymans 2019). The virtual layers in this software consist of markings that are laid over a camera image of the environment and so help the user navigate it. In professional settings, this function is also used to provide pilots, police officers or soldiers with additional information about the environment in their field of vision, so that they can better perform their tasks.

Manipulation function

A second function of AR as an interface is to manipulate reality. This usually involves interactive overlays that distort the perception of the environment. Most of the examples given in this report (also) serve this function. One may think here of apps that create environments in which monsters run through the streets, in which non-existent buildings can be seen or in which people's faces are filtered. Also experiments with the projection of holograms of deceased stars during public performances (Tsukayama 2012) belong to this category. Here, the technology creates a sensory illusion: the senses of the user or spectator are basically 'fooled'.

Communication function

Facilitating communication is an AR function of a somewhat different order. In recent years, communication functionalities such as microphones, headsets and communication platforms have been integrated into AR applications. Such functionality enables users to meet with each other in a hybrid environment, to play video games together, or to work in teams (for example, designing a building with a group of people) (Kelion 2019).

The use of filters also can be seen as a form of communication, since users increasingly use AR layers to express their thoughts or feelings, or even to assume specific (alternative) identities. This happens among others on platforms like Instagram or Snapchat, where people use AR filters to improve their looks or alter their appearance. AR thus becomes an important part of the message and identity that users wish to convey. This way, the use of real-time filters transforms the hybrid AR environment into a new socio-cultural environment in which meaning is created and shared.

The immersivity of AR
Like VR, AR can trigger a highly immersive experience for users: the feeling that they are submerged in the hybrid environment (see also Rathenau Instituut 2019). Here we briefly discuss a number of factors that contribute to this immersivity.

The first factor is the multi-sensory character of AR. People's perception of reality is generally also multi-sensory: they hear, smell, taste, see and feel the world and experience it as a 'sensescape'. By modifying the user's experience of the environment, an AR system creates a highly *personal* sensescape: a sensory panorama tailored to the user (cf. Lemley & Volokh 2018). The choice of AR functionalities, and specifically which senses they address and how many at the same time, determines to a great extent the nature of a user's experience.

The dynamics of the hybrid environment is another factor that determines the immersivity of the user's experience. With AR, virtual layers constantly adapt to the users' movements: to one's location, but also changes in one's posture or line of sight. If the layers smoothly follow the physical environment in which they are anchored, the hybrid environment appears dynamic. There is a relation here with the workings of the data-processing technology: how the technology links the virtual layers to objects or locations, and whether those layers are generated in real time or are pre-programmed.

Another factor that contributes to the nature of the AR experience is the type of information presented to the user: whether it is photographic or graphic, an information overlay or an interactive overlay. Highly dynamic versions of AR often 'blend' different sensory layers. In this context, 'blending' means that the physical and virtual environments merge seamlessly, the result being that the user can experience them as a single entity. This feature is crucial for users who want to immerse themselves entirely in an AR simulation. However, blending can also make it more difficult to distinguish 'real-life' from 'fake'.

2.4 AR devices

A wide range of devices is available for presenting hybrid environments. We can roughly divide them into four categories or groups: projectors, head-up displays (HUDs), hand-held devices (such as smartphones and tablets) and wearables (such as smart glasses, headsets and smart earbuds). Table 2.2 gives an overview of the four types of AR devices, with a product example in each category.

Overview of AR devices

Devices	Projectors	Head-up displays	Hand-held devices	Wearables: Smart glasses	Wearables: Headsets
Product example	Lightform	Wayray Navion	IPhone	Google Glass	HoloLens
Sample application	Projection art	Navigation	*Pokémon GO* (gaming)	Vision picking	Neurosurgery
Data collection*	Depth	Depth Location Markers Speech Hand movements Platform data	Depth Location Touch Platform data	Markers Platform data	Depth Markers Head movements Hand movements Speech Platform data
Data analysis*	Projection mapping	Spatial mapping Position tracking Image recognition Speech recognition	Spatial mapping Position tracking	Image recognition	Spatial mapping Speech recognition
Data application*	Information display Information overlay	Information display Information overlay Interactive overlay	Information display Information overlay Interactive overlay	Information display	Information display Information overlay Interactive overlay

**The content in the table is based on the product example and the sample application*

Figure 2.2 Overview of AR devices

Source: Rathenau Instituut

Projectors

If AR environments are created with a projector, the result is generally referred to as 'projection-based AR' (Cebulla 2013). As this term indicates, an image is projected onto an (existing or purpose-built) surface, possibly in combination with an audio layer. There are simple as well as more complex versions of projection-based AR. In the case of simple projections, a single visual layer may be projected onto an object, such as scale model of a building, in order to 'bring it to life'. In more complex versions, the visual layer is not static but dynamic and interactive. In order to produce such results, one needs both a projector and a camera, in order to register depth and movement so that the system can respond to the user's actions.

With the use of projectors, collective AR experiences become possible: a number of people can observe the image and/or sound at the same time. For this reason, they are popular at public events such as concerts, plays or art exhibitions. During the annual Glow Festival in Eindhoven, for instance, projection-based AR is often used to transform buildings and objects into works of art (projection mapping).

Head-up displays

Another type of device that can be used to display AR environments is the head-up display (sometimes also known as 'heads-up display') or HUD (Marín et al. 2016). This term is used for an arrangement consisting of a transparent screen in the user's field of vision, and a device, such as a small projector, to display data on that surface. The advantage of such a set-up is that the user can receive information without having to look away from the image on the transparent screen. This explains why HUDs are often integrated into vehicles, where they are used as a driver's aid. An example of this application is the projection of information about location, speed or altitude onto the windshields of cars or planes.

Hand-held devices

The most accessible and currently most popular method of experiencing AR is with the help of a hand-held device, such as a smartphone or tablet. The mobile telephone has played a major role in the proliferation of AR. The rise of the smartphone around 2007 not only led to an increase in the use of the technology, but also prompted the development of forms specifically designed for mobile use, collectively known as 'mobile augmented reality' (Arth et al. 2015).

Modern smartphones contain functionalities for navigation, to make photos and videos, to recognise faces, objects and speech. Provided they have access to the necessary software, they can also be used for AR applications. AR for the smartphone is usually operated with a touchscreen, and sometimes by voice, hand gestures or facial movements. Very popular consumer applications for the smartphone include social-media apps such as Snapchat (since 2011) and games like *Wizards Unite* (2019).

Wearables

The last type of device we discuss here is the category of wearables. For AR, we can make a distinction between smart glasses and headsets (or head-mounted displays, HMDs, which are quite literally placed onto the head rather than onto the nose). Smart glasses and headsets are similar to HUDs in the sense that there is always a transparent surface that the user can look through and onto which digital layers are projected. The most important difference is that with wearables, this surface is worn directly on the body. The AR experience always has a visual component, but it is often combined with sound (sometimes via integrated earbuds) and/or haptic feedback (via a controller or another wearable).

Besides smart glasses, there are also more complex wearables such as the HoloLens, produced by Microsoft (2016), and the Magic Leap, manufactured by the eponymous company (2018). Both devices can map the environment with the help of cameras, thus producing an interactive overlay of (three-dimensional) virtual objects that are linked to elements in the physical environment. They can also produce photos and videos and recognise faces and speech, as well as to register and save eye, head and hand movements. This combination of functionalities enables users to perform actions with virtual objects.[1] Such HMDs are currently used mainly in the professional sector.

Smart earbuds

Smart earbuds are a sub-category of wearables.[2] They are also known as 'augmented hearing devices' (or *earables*), because they modify the perception of sound (Martins 2018). Smart earbuds process digital sound such as music, a caller's voice, or sound from a navigation system or virtual assistant. For example, they can automatically lower the volume of the music one is playing, if a call is coming in. Virtual assistants such as Siri, Alexa or Google Assistant are often integrated in earables (as well as in hand-held devices, other wearables and loudspeakers) and project AR audio layers over other sounds that enter via the earbuds.

Smart earbuds process sound from the user's physical environment by first recording the noise in the environment and converting it into digital signals, and then analysing and processing it into modified sound. Signals from the environment can also be suppressed. Such noise control can be 'passive', if the earbuds are designed in such a way as to prevent certain noise from reaching the user's ear. But it can also be 'active', meaning that noise reduction or noise cancellation is used, in which case the earbuds measure the strength of the noise outside the earbud and generate an 'antiphase soundwave' to (partially) prevent the noise from being heard (Williams et al. 2002).

Finally, noise from the environment can be amplified. This is done by manipulating the signal on certain frequencies – for instance, frequencies where much of human speech occurs – to make the sound easier to understand. In this way, hearing aids can improve users' ability to hear and distinguish sounds, thus enabling them to concentrate on the most important ones. McGreal refers in this context to 'super hearing' (2018, p. 261). AI, particularly machine learning, plays a key role in this process (Nuheara 2019; Baranov 2018). In 2017, Google demonstrated an earbud that is capable of translating forty languages by means of AI, almost in real time (Gershgorn 2017).

1 Because the objects can blend with the environment and the user can also perform actions with them, product developers sometimes call this form of AR mixed reality. However, the conceptual distinction with other headsets is not very sharp; the term is used mainly for marketing purposes.

2 Apple is the leader in this market, followed by China's Xiaomi and South Korea's Samsung as the second- and third-largest producers, respectively (see Poort 2019).

2.5 Visions on the future: from AR to augmented humans

There has been intense speculation among journalists and developers in recent years about the future development of AR technology. The significance of these utopian visions should not be underestimated, because they are often endorsed and pursued by large tech companies with the power, both technological and economic, to actually shape important elements of those visions. Zuboff speaks in this context of ‘applied utopianism’: the practical pursuit of a vision (2019, p. 404). In this section we briefly sketch a number of important vistas that are being chased with forceful rhetoric and considerable investment of resources.

Convergence of VR and AR
Although we make a clear distinction between AR and VR in this report (see chapter 1), the boundaries between the two types of environment are fluid, and there are numerous examples of products in which they are combined. Some authors expect that in the future, people will be able to determine for themselves which part of their AR experience involves the virtual world and which part the physical – and that users will be able to constantly switch between the two worlds (e.g., Mann et al. 2018). The latest developments in AR systems confirm this impression and suggest that we will more often see this convergence of AR and VR. Advanced headsets from Microsoft and Facebook, for example, allow their users to decide for themselves which part of their environment involves the virtual world and to switch between virtual, hybrid and physical environments. As AR systems become more powerful and smaller, we can probably expect an even wider range of combinations of the physical and the virtual.

Ubiquitous AR
Large companies such as Facebook and Snap see the hybrid environment as a natural successor to the two-dimensional internet we have today and to contemporary social media platforms. The mouse, keyboard and touchscreen, in this scenario, will be replaced by a physical-virtual world that can be operated intuitively with physical movements and voice. Snap, the company behind Snapchat, announced this year that it is developing its own digital platform (Hern 2020), which would make the camera the centrepiece of interactions between humans and machines, whereby AR ‘has tremendous potential to change the way we see the world’ (Hern 2020). Niantic, a spin-off off from Google and a market leader in AR with such products as *Pokémon GO* and *Wizards Unite*, is building a Real World Platform. This is an AR platform on a ‘planetary scale’, where AR producers can use the entire world as a gameboard for their own applications (Hu & Wu 2019). Meanwhile, Niantic has formed an alliance with a number of major telecommunication companies, including Deutsche Telekom, EE, Globe, Orange,

SK Telecom, SoftBank, TELUS and Verizon, to promote 5G and to build the mobile infrastructure for a permanent, global AR network (Hu & Wu 2020).

Technology producers in particular foresee a future in which users will find themselves permanently in a (more or less) hybrid environment. Stephen Lake, the CEO of North, the company that produces the Focals smart glasses, claims it is his ultimate goal to produce a wearable that users 'can wear all day, every day' (Smith 2019).

The visions of Lake and others can be traced back to ideas about ubiquitous computing – a term coined by the American computer scientist Mark Weiser (1991). Weiser forecasted that in time, people would be assisted in all of their daily activities and needs by information technology. Computers, steadily downsizing and therefore becoming more invisible, his expectation was, would become ubiquitous. AR is reviving this idea. In 2020, the start-up Mojo Vision announced that it wants to offer smart AR contact lenses within three years (Kastrenakes & Carman 2020), which would make the technology practically invisible.

Seamless and realistic AR

Sandor et al. (2015) refer to 'true AR' in cases where the user is unable to notice the difference between the physical and the virtual environment. Companies are actively investing in the development of this sort of 'lifelike' simulations of our interactions with the world. For example, Facebook is currently engaged in a project entitled Codec Avatars, the aim of which is to produce extremely realistic copies of humans and their behaviour with 3D sensors and artificial intelligence, in order to facilitate virtual meetings that are indistinguishable from physical meetings (Facebook 2019a).

According to Poppy Crum (2019), a researcher at Dolby Laboratories, smart earbuds may be used within years as a portal to various biometric data: body temperature, heartbeat, brain activity, oxygen levels in the blood, the hormonal system, the nervous system and more – a sort of biological equivalent of the USB port. Such biometric data could be used for instance to automatically adapt the sound intensity of an application to the user's perceived stress level. Digital sound and its intensity would then no longer be distinguishable from analogue sound.

Alex Kipman, the designer of Microsoft's HoloLens 2, further expects that our hybrid AR environment will feel increasingly natural (Kipman 2016). AR developers (e.g., Fan et al. 2019; Araiza-Illan et al. 2019) generally place great emphasis on the intuitive nature of their applications, particularly for specialised, professional applications.[3] The intuitive nature of AR also takes centre stage in reflections on the future of the technology. Kipman expects that eventually, users will no longer have to think about their interactions with AR at all (see Kehe 2014). Here, a lot is riding on the operation of devices, as well as on their capacity to gather large volumes of (personal) data and process them in real time. This latter property will allow for personalisation: the tailoring of the technology to an individual's personal needs (Schuurman et al. 2007, p. 13), so that the physical and virtual environments can be matched seamlessly to each other.

Developments in the field of AR come with the promise that in time, we will be able to 'feel' one another, by means of applications that use haptic feedback to simulate being touched by others. In VR, this type of interaction is already being feigned. The documentary *I Met You*, by the South Korean broadcasting company MBC, shows a mother being reunited with her dead daughter in this way (see figure 2.3) (Japan Times 2020).

Figure 2.3 Image from the TV documentary *I Met You*

Source: MBC 2020

Mirror Worlds

A related, but slightly different, future scenario concerns the existence of a virtual mirror world. In 1991, computer scientist David Gelernter published the book *Mirror Worlds*, in which he predicted that digitisation would lead to a digital mirror image of reality. This 'downloadable' mirror world would allow individuals to visit and explore places without moving. Even in 2021, we digitally mirror the world in numerous ways: applications like *Google Maps* already provide a sort of digital mirror of the

3 On YouTube there are already numerous demos to show the quality of new applications, for example with the use of robots for material processing (https://www.youtube.com/watch?v=4MSIy4TC6zs) or medical interventions (https://www.youtube.com/watch?v=o2O38ZMkXXI).

world using satellite images, aerial photos, maps, 360º camera images, real-time traffic information and virtual objects. Our employers, our governments and we personally help to create such a mirror world by sharing data about our bodies, our production processes or our public spaces. In this way, we help produce more and more 'digital twins', or objects that are linked, directly and in real time, to digital counterparts.

Kevin Kelly, editor of the technology magazine *WIRED*, argues that AR headsets now make small pieces of this mirror world visible. But 'piece by piece, these virtual fragments are being stitched together to form a shared, persistent place that will parallel the real world' (Kelly 2019). Technology companies are currently competing to become the pioneer and market leader in this field. Facebook is building an AR cloud called *LiveMaps* (Facebook 2019b). The application is intended to create a true size, three-dimensional copy of the world, which can be explored with a mobile phone or an AR headset.

Augmented Humans

Transhumanists want to enhance the physical and cognitive capabilities of humans through nanotechnology, genetic technology and information technology. They foresee a deep integration between humans and technology; humans will become *cyborgs* who evolve into 'post-humans' via technological upgrades. For transhumanists, prostheses, such as glasses, hearing aids and artificial limbs, are early indicators of this trend. Portable AR systems are the prostheses of the future, which will improve the cognitive and sensory capacities of humans in various ways.

Consequently, AR heralds a new phase for humanity: the era of the Augmented Human or Human 2.0. According to Alistair Croll, 'Human 2.0 … is a person imbued with superpowers that let him learn, play and love in new ways. It's also a society, rethinking how to vote, govern, prosecute, cure and comfort' (Croll 2010). Among these superpowers are the ability to speak every language, always knowing the quickest way to get somewhere, total recall, and always being able to talk to anyone. Through its information, manipulation, and communication functions, AR in part realizes this vision.

2.6 Conclusion

In this chapter we have explained how AR works. We found that the quality and amount of sensors and data that are used to construct hybrid environments is expanding all the time. Movements of head, eyes, fingers and arms are constantly monitored with advanced cameras in order to build a hybrid environment that is as accurate and interactive as possible. These sensors register a lot of environmental data, and in the process they map objects, other users but also non-users, in order to incorporate them in the hybrid environment. The data often includes very intimate information about users and non-users, which can be used to produce and share unique, identifiable data profiles.

By processing this data, an AR system creates a personal sensescape: a sensory panorama tailored to the user. This may entail a highly immersive user experience – particularly if the simulation contains multi-sensory input, is of high quality and contains dynamic and interactive elements. Reasoning from the user's perspective, AR can be understood as a digital prosthesis that may enrich one's experience of reality by supplementing information about the environment, by enabling manipulation of this environment at will, and by offering a communication platform.

AR can be experienced with an ever expanding range of devices, including smart glasses, headsets and projectors – all of which offer slightly different experiences. The rapid developments in these devices is driven in part by utopian visions of the technological potential of AR. A number of future scenarios, supported by wealthy investors and technology developers, present to us a world in which AR is ubiquitous, almost invisible and impossible to distinguish from the real world. In such vistas, the hybrid environment is the next step in the evolution of the digital world. We are moving from two-dimensional internet and social media that we operate with a keyboard, mouse or touchscreen, to a hybrid platform with VR/AR technology and biometric control. Work is already being done to make such hybrid platforms possible. They are based in part on digital mirroring of the physical reality.

In the next chapter, we shift our attention to the societal impact of AR. Using practical examples, we look at the use of AR technology in a variety of social contexts.

3 AR in practice

3.1 Introduction

In this chapter we explore the current state of AR usage. We present six practical examples, which are based on interviews. In discussing these examples, we aim to give an impression of the application of AR in various domains, specifically in the Netherlands. The examples show what AR delivers, and in the process also reveals technical or economic constraints, but also social frictions that users and developers currently encounter.

In selecting the practices, we have tried to find a balance between applications in different markets and different phases of development. The first four practices are applications for the professional market, where AR applications are currently experimented with and where as a result, a lot of innovation is taking place. According to a report by the Dutch branch of the AR/VR Association at the end of 2019, at least 53 Dutch companies were engaged in developing AR and VR products at the time (VRARA 2019). Roughly three-quarters of the companies were developing applications for specific (professional) sectors.

We discuss, in this order, the use of AR in neurosurgery, in the construction of a bridge, in the marking of ship decks and in supporting the work that is carried out in distribution centres. The last two examples we deal with are applications for the entertainment sector, where AR applications have reached a wide audience via mobile phone applications. The fifth example concerns the well-known AR game *Pokémon GO,* which caused considerable uproar when it was played by large crowds of people in The Hague. The application in the sixth example is *Mirror Worlds* – the game devised by artist Roos Groothuizen for the Rathenau Instituut. We discuss a test of the game carried out by a group of students at Central Station in The Hague.

In selecting these practices, we have considered the types of AR systems that are used in each case, the type of application involved and the phase of development of this system of application. The applications covered are intended for use on complex headsets (AR in neurosurgery, bridge building and deck marking), simple headsets (distribution centres) and mobile devices (*Pokémon GO*, *Mirror Worlds*, both of which can be played on a smartphone). Some of the applications reviewed here are still in the phase of research, development or demonstration (AR in neurosurgery and bridge building). Others have already proved their market value or can be regarded as technically feasible and profitable products (AR in deck marking and distribution centres). As regards the professional applications that are still in the experimental phase, it can be expected that if there is sufficient interest, they will be further developed and marketed on a larger scale.

Mirror Worlds differs from the other applications discussed, in that it was not designed for a commercial purpose. In this case, furthermore, the experimental nature of the game was part of its concept – not a stage in its development. *Mirror Worlds* was designed to assess observations that were made in the course of this study in an artistic manner, and as such, to provide new insights into the phenomenon of AR. For this reason, the discussion of the attendant practice takes a different form than in the other cases. Here also, we review the experiences of users, but in addition, we also reflect on the role of the app's development within the context of our research.[4]

In this chapter we devote attention to the benefits users derive from AR, but also to the technical constraints that developers face and to the societal issues raised by the practical application of AR. As mentioned in chapter 1, we focus here on three types of societal issue: data issues, manipulation issues and spatial planning issues. In the concluding section, we summarise the various technical challenges and societal issues.

3.2 AR in neurosurgery

The health care sector is experimenting with AR in various ways. The technology is used here to communicate with patients in new ways, but also for training purposes and in diagnostic practice. In order to gain a better understanding of the potential uses of AR in health care, we spoke to neurosurgeon Tristan van Doormaal of the University Medical Centre Utrecht (UMCU) and software developer Tom Mensink.[5]

Clarifying a medical problem

Since the 1970s, doctors have been using CT scans and MRI scans to map the brains of patients. Such machines produce a series of black-and-white images of two-dimensional cross-sections of the brain. Understanding and analysing those images requires training. Neurosurgeon Tristan van Doormaal says that in using such scans, he was unable to properly explain to others what exactly what the issue

4 See also the interview with Roos Groothuizen and Dhoya Snijdes about the added value of artistic-design research on our website: https://www.rathenau.nl/nl/digitale-samenleving/kunst-en-wetenschap-onderzoeken-samen-urgente-vragen

5 Interview with Van Doormaal conducted on 9 October 2019, by video connection; interview with Mensink conducted on 23 October 2019, in Utrecht. A follow-up of these conversation took place on 21 September 2020.

with a brain was, and what its three-dimensional image represented. 'I couldn't explain it to patients', he notes, 'but not to young surgeons either.'

The experience prompted him to start experimenting with AR, because with AR, it is possible to generate a hologram on the basis of data from a CT or MRI scan. A doctor can then study and discuss the hologram with a patient, with the help of AR headsets. Surgeons, assistants, students and patients all benefit from this, because it can deepen their understanding of a medical problem. AR can help, for instance, in visualising a planned operation. But the technology can also be used as a training instrument. At UMC Utrecht, Van Doormaal is working on a training set with holograms of real patients, which illustrate diseases that occur in medical practice.

Help during operations

AR can also be useful during the actual performance of an operation. A hologram is a fairly precise, virtual copy of a patient's brain. If a hologram is projected onto the patient's head during an operation, the surgeon can see dangerous structures and zones in the area he or she is operating on.

AR is a form of 'intra-operative imaging technology'. 'Intra-operative' means that a second scan of the brain is made even before the patient leaves the operating theatre. The head is temporarily closed and the patient goes through the MRI scanner again. On the basis of the new scan, the surgeon can determine whether a tumour has been removed entirely. 'If we see that a part of a tumour remains', says Van Doormaal, 'we can make a new hologram in five minutes'. He hopes that AR will shorten the time operation takes and increases the chances of a successful operation.

Technical challenges

Although the technology is developing rapidly and many problems have already been resolved, users still face technical challenges in experimenting with AR as a surgical aid. A persistent problem is the battery life of the headset that Van Doormaal uses, which is shorter than the duration of most operations. At the time the experiments began, the greatest technical challenge was producing a hologram. This required a lot of preparation, including a great deal of sketching. A pipeline has now been developed for automatically converting a scan into a hologram. Moreover, it is now possible for users – thanks to a European research subsidy (Eurostars Grant) – to immediately identify, with the help of artificial intelligence, structures that might suggest a tumour in the brain on the hologram. Another challenge was that the HoloLens 1, the type of headset that Van Doormaal initially used, produced a very narrow field of vision for the user. With the HoloLens 2, however, the user's field of view has already widened considerably.

Because the patient’s head is entirely steady during a brain operation, neurosurgery makes logical starting point for the application of AR in surgical practice. But operations of this type usually involve a team of surgeons and assistants. And in practice, it is quite a challenge to ensure that a hologram (the virtual object) and the head onto which the hologram is projected (the physical object) remain perfectly aligned for the person who is operating – also *while* a surgical action is being performed. Moreover, the other members of the operating team must be able to observe the surgeon’s movements during the procedure, each from their own perspective.

Even if it is possible to rarther precisely project a hologram onto the location of a brain, Van Doormaal points out, this can create problems. ‘Let’s say a blood vessel starts bleeding. Then there is something projected over it that may need to be removed before you can deal with the bleeding.’ For this reason, his team has now patented a technology for projecting a hologram slightly above the patient’s head so that the projection does not obstruct the operation itself and the hologram works as a sort of crib sheet.

Requirements and procedures

In order for a new medical technology to be widely used, various quality standards and formal safety rules need to be observed. Developing AR for health care is therefore a lengthy process. Moreover, the buying of hardware is a major investment for hospitals. New products or technologies have to fit in with the existing working methods, and they cannot be adopted unless repeated studies must have yielded positive results.

Finally, medical equipment must also be safe. Every device that is introduced in the operating theatre must have CE certification. Equipment needs to meet the safety requirements laid down in the European Union’s Medical Device Regulation (MDR). The team that was involved in developing the use of AR at the UMC Utrecht is currently following this procedure and hopes to soon have a first approved product.

Data and privacy concerns

When digital medical imaging technologies are used, various intimate data of patients are collected and processed. It is therefore imperative that the management of their data and the protection of their privacy is considered. There are specific security requirements for the storage of health-related data. Hospitals also have their own rules for access to and handling of data. But devices such as the HoloLens do not yet have the status of medical equipment, which raises the question of whether the data they collect are properly managed. How are the rights of patients safeguarded when digital medical devices such as the HoloLens are used?

Van Doormaal informs patients in advance of the use of the AR images and requests their consent for use. Among others, he informs them that he will use the images for training purposes. In practice, he only uses them in the context of his own hospital. Privacy legislation such as the GDPR does not allow him to share the data with other care institutions.

The holograms are currently stored in the Azure Cloud, a service provided by Microsoft (the company that also developed the HoloLens). This is the same cloud where hospitals store other patient data. For this purpose, he uses a self-built and certified secure environment. Access to this environment is controlled by iris recognition. The parties involved regard this is a 'revolutionary' form of security, which should also make it possible for hospitals to exchange data in the future. 'Data that is stored locally,' Tom Mensink explains, 'are rendered unreadable by third parties with modern encryption techniques.' Despite such precautions, anyone using a commercial cloud service is dependent on a large technology company. Such companies are generally also interested in medical data, as they can sell them. From the perspective of privacy, therefore, it is necessary to constantly monitor the terms of use of their services.

3.3 AR in the building of the Boekelo bridge

Aside from being used for medical purposes, AR also supports various production processes. To illustrate this, we discuss an example from the construction sector: the building of the Boekelo bridge in Hengelo. To learn about this project, we spoke to Dura Vermeer's project manager, who was responsible for building the bridge.[6]

Clarifying the building process
Construction makes use of design drawings. These are three-dimensional drawings: they have a height, breadth and depth. Working in 3D is necessary because complex building works have parts that cannot be properly represented on a flat surface. The Boekelo bridge, for example, has various curves that would otherwise not be clearly shown. But in order to use drawings on a building site, they need to be printed, which is currently only possible in 2D. This makes it difficult for the people who are building the bridge to envisage the final result and the steps that have to be taken in order to reach it.

Here also, AR seems to offer a solution. During the construction of the Boekelo bridge, the original, digital 3D design could be viewed on the site with a headset. A digital hologram of the bridge, which was projected across a river, was used for this

6 Interview conducted on 28 October 2019, in Utrecht.

purpose. This allowed the builders on the site to view the bridge from different sides and made the building process easier.

New technology in a traditional sector

The construction sector is perceived a highly bound by tradition. Sometimes, this makes it difficult to introduce innovations. The experiment with the use of AR in the construction of the Boekelo bridge was part of a project subsidised by a regional authority (the province) in order to promote innovative design. Because of this, there was scope to try out novel working methods.

Initially, stakeholders were not universally enthusiastic at the prospect of the experiment. Some were concerned about the accuracy of the holograms in relation to the design drawings. In practice, such scepticism quickly evaporated, because working with a hologram was found to be highly intuitive. Operating a headset may take some practice, but the image one sees is easy to interpret – whether for a production planner, a foreman or a carpenter. It is immediately clear where there are cables or pipelines in the ground, or where certain parts need to be placed.

Technical obstacles

A lot of modifications were necessary in order to make the HoloLens suitable for use in construction. For example, the headset had to be fitted with a sunscreen so that users could also see the image properly in bright sunlight. To fix the representation of the bridge in the correct position in relation to the physical space, a GPS antenna and a digital compass had to be supplemented. The materials also had to be weatherproof and wind resistant, capable of withstanding a blow and be user-friendly. The proof of concept did not yet meet those criteria. 'This mushroom on your head weighs 4 kilograms and wobbles,' says the project manager, referring to the set with GPS antenna.

Furthermore, the digital model had to be simplified because otherwise, the file holding it was too large for the HoloLens to manage. Other functions, such as the possibility of modifying a design, had to be deactivated, since AR was intended here purely for visualising and measuring; the image therefore had to be frozen. A carpenter, after all, should not be able to accidentally position the bridge twenty metres further up.

Innovative working methods

In the case of the Boekelo bridge, AR enhanced the mutual understanding between the bridge's designers and those who did the building. The fact that the latter could clearly visualise what needed to be done even partially eliminated the need for in-person consultation. Moreover, parts of the communication and cooperation could be conducted remotely. Thanks to the headset's remote-assist function, people who were not actually on the building site could watch along with the builders and so help to avoid future problems.

In other words, AR meant that users behaved differently in their work – particularly in relation to one another. Their collaboration was different, and this immediately made the work process more efficient. It was also found that the use of holograms increased the workers' enjoyment of their work. The physical-virtual domain made complex work slightly easier and more imaginative.

3.4 AR in deck marking in the logistics sector

In addition to the above, AR is used to optimise work processes in the logistics sector. The example we discuss here is Jumbo Maritiem, a company that ships heavy loads. It uses AR in the process of marking the deck prior to the loading of a ship. We learned about the practice in an interview with developers from Wortell, the IT service provider that developed the application used by Jumbo Maritiem.[7]

Virtual deck marking
Deck marking is the process of marking a ship deck to show the precise positions of the cargo that is to be transported. In principle, this is done manually, with the help of a technical drawing, a tape measure, chalk and a can of spray paint. Because the drawing is to scale, it takes two engineers two days working on site, to calculate precisely where the markings should go. This makes the process expensive – also because in the meantime, the work of the ship's crew comes to a standstill. Furthermore, measurement errors cannot be ruled out with this method.

Jumbo Maritiem developed a way of optimising the deck-marking process. In association with IT specialist Wortell, the company found a solution in the use of AR. As with the examples of UMC Utrecht and the Boekelo bridge, Jumbo Maritiem uses the HoloLens, which enables a user, as it were, to project a technical drawing onto the deck so that it can be seen in its actual proportions. The physical marking is now a matter of transposing the lines that the user sees to the surface in front of him. Such practice is particularly useful in the case of complex cargos. It entails that the job of deck marking can be completed in a few hours and can be carried out by less specialised employees. The engineer who produces the design can send the drawing directly to the ship's captain and a crew member can then do the marking. This contrasts with the situation it substitutes for, in which engineers had to fly to (often remote) locations to help with the deck marking.

Technical challenges

7 Anonymised interview on 16 November 2019 in Lijnden.

The biggest challenge in the project was that the entire drawing could not be projected at once, because of a combination of two factors: the size of the database, and the range of the cameras in the headset. This limited the image to a radius of three metres around the employee, which meant that only part of the total area could be seen at any one time. Every movement generated a new partial image. Employees of Jumbo Maritiem speak in this context of the ‘Billy Jean method’ – a reference to the Michael Jackson music video, in which tiles light up as the singer steps on them.

Another constraint was that the method does not allow the deck to be marked while the ship is being loaded or unloaded. This can cause the digital drawing to ‘sink into’ the physical deck when a heavy load is on board or the weight of the load changes. The ship must therefore be entirely still to use this method.

Privacy issues
Jumbo Maritiem is currently using the HoloLens, which employs cameras to match a technical drawing accurately to the physical environment. This can become a problem if there is a cargo on board while the markings are being positioned on the deck. The client might, for example, object to a cargo being filmed for reasons of privacy. This problem can in principle be resolved by switching off the recording function. But the headset also has a remote-assist function, for which images have to be transmitted. The privacy risks that this entails are more difficult to address.

Working more efficiently
The main appeal of AR for a company like Jumbo Maritiem is that the technology allows for the work to be performed more efficiently. This in turn yields substantial cost savings – not only in terms of wage cost (for deck markers and other staff members), but also various overhead costs, such as port charges for the vessel. Of course, the ensuing profits mainly benefit employers. But employees also seem to like using AR, as it means they spend less time doing boring jobs or just waiting around. Generally, however, they only come to realise this when they have actually used AR. Prior to doing so, many are wary of using technology that could drastically alter their working methods. This highlights the importance of properly informing employees and consulting them on the conditions for the use of AR.

3.5 AR in distribution centres: vision picking

In the logistics sector, experimentation with the use of AR is widespread. A number of companies in the Benelux already use smart glasses. They include Nox (a company specialising in night-time distribution), the technical wholesaler Flos, the telecom company Samsung, the e-fulfilment company Active Ants and various AR service providers (Dijkhuizen 2017). We assessed the status of AR use in distribution centres by speaking to Tjalling de Vries, who is responsible for innovation projects at a large distribution company, and Johanna Bellenberg, the director of marketing and communication at Picavi, a developer of AR solutions for the sector.[8]

Order picking in distribution centres

With the rapid growth of e-commerce, distribution centres play an increasingly important role in modern logistics. Parties in the sector compete on the basis of their response time and therefore have a major interest in efficient working methods (Lu et al. 2016). This partly explains the heavy pressure they are under to improve their processes.

Distribution centres commonly use various forms of information technology. The printed distribution lists such companies used to work with, really are a thing of the past. But the sector still depends heavily on human workers. Warehouse workers, or order pickers, play a key role in the operation of distribution centres. They are responsible for unloading, inspecting and sorting the goods on arrival, storing them in the right place and then preparing them for dispatch and loading them. Bellenberg observes that people are in fact the major success factor in logistics at the moment, because of their cognitive skills and flexibility. But new digital technologies can assist them in their work and improve their efficiency.

Digital tools in the logistics sector

Various digital systems are currently in circulation to assist order pickers in their work: mobile data terminals, pick-by-voice systems and pick-by-light systems (Schwerdtfeger et al. 2009). The first is essentially a barcode system, which supplies an employee with instructions on the screen of a handheld scanner after scanning a package. Pick-by-light systems use special shelving, which is fitted with lamps so that the employee can follow instructions. Pick-by-voice systems use a headset and microphone for spoken instructions.

A more recent development is pick-by-vision (Reif & Günthner 2009) or vision picking, a system that works with AR wearables. Ideally, such wearables combine the functionalities of the aforementioned systems: visual instructions, voice instructions and instructions via barcodes.[9] A feature that pick-by-vision shares with pick-by-light and pick-by-voice is the fact that the warehouse worker does not have to hold a device or look down at a screen to read instructions (as is the case with a mobile data terminal). This has benefits in terms of safety, since users then have their hands free and maintain an overview of the space. Pick-by-vision has the flexibility of pick-by-voice in that it does not depend on an existing shelving system.

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8 Interviews with Johanna Bellenberg on 29 June 2020 and with Tjalling de Vries on 1 July 2020 via a video call. There were e-mail follow-ups with both respondents in September 2020.

9 The latter is then scanned with either a built-in scanner or a scanner that is worn around a finger.

However, the advantage of vision picking is that the visual instructions also work in a noisy environment.

The wearables used in distribution centres are generally simpler than those used in the sectors discussed earlier. Google's Glass Enterprise 2 is particularly popular. These smart glasses have a single display in the corner of the user's field of vision and are roughly the same weight as regular spectacles, which means they can be worn comfortably during long shifts. Bellenberg stresses the importance of a simple and intuitive graphic interface, as this further enhances their user-friendliness. But it also means that employees can be quickly trained in working with the glasses. The software designed for De Vries' company of therefore mainly uses illustrations and small icons.

Fewer physical obstacles

AR systems can be used in distribution centres in a variety of ways. De Vries' company uses them to instruct warehouse staff which shelving unit they need to go to, which products they have to collect and where they have to bring them. In some logistics companies, drivers of vehicles also use AR systems to help them with navigation.

The main appeal of AR systems for employees is that they make their work less physically arduous or complex. In an interview with the Dutch newspaper *NRC Handelsblad*, a DHL employee said that he preferred using smart glasses over a mobile data terminal. Working with a handheld scanner, he argued, hurt his arm. He also found it irritating to constantly have to put down the scanner to lift or cut open boxes. From the employer's perspective, the efficiency gains are the most important benefit of AR. In the words of the same employee: '[I] never [used] to meet my targets, now I always exceed them' (Pelgrim 2019).

Researchers anticipate that in the future, AR will do more than to help lighten or simplify the work of employees. They also expect, for example, that the technology will be used more often as a sort of interface between humans and robots (Jost et al. 2018). In places where some of the work is automated, AR could help to coordinate the movements of humans and robots. Glasses would monitor the locations of their users and, by linking the resulting data to data about the position of self-driving robots, collisions could be avoided. In this way, AR glasses would contribute to workplace safety, but also to employees' feeling of safety (Jost et al. 2018).

The costs and benefits of AR

However, if AR is to be interesting for large-scale use in the logistics sector, the designers of systems first have to overcome a number of technical obstacles. For example, the existing hardware is not yet ideal for use for lengthy periods. Smart glasses have a short battery life. Processors can also become overheated after a time. Screens do not yet adjust to the light quality in the environment (for example, when moving outside from indoors). According to researchers, this can cause headaches or tired eyes (Stoltz et al. 2017). A study to this effect has in fact prompted De Vries' company to restrict the use of smart glasses to a maximum of two hours at a time.

At present, the benefits of investing in AR technology for companies do not yet outweigh the expense. Tjalling de Vries and Johanna Bellenberg estimate the efficiency gains from working with smart glasses compared to using a simple handheld scanner at fifteen, respectively thirty percent. The relative gains compared to a pick-by-voice system are smaller. Moreover, in order to enable people to work with AR, companies not only have to buy the glasses and have the necessary software developed or implemented; they also have to allow for training costs and possibly the cost of modifications for employees who need special glasses (with prescription lenses, for example). And if a company's internal IT team is not able to maintain or expand AR equipment itself, there are further external costs to consider.

Concerns about data processing

The use of AR in the logistics sector also raises questions about how companies handle data. The smart glasses used by order pickers contain cameras, microphones and other sensors. Those sensors collect a variety of data about the users' actions: the number of steps they take, the route they walk, the number of barcodes their scanners register. The system needs those data to function properly. Managers and process engineers might also use this data to improve work processes. Data from smart glasses could, for example, lead to changes in the layout of a warehouse to enable employees to move around more quickly or to reach certain products more easily. Or they could be used to provide users with personal feedback or advice. For instance, game elements could be added to the work process, such as a star system for completed tasks, a scoring system, or feedback on the employee's performance – possibly even in comparison to his or her earlier performance or that of colleagues.

The same data, however, could also be used to monitor employees or to manage or evaluate their performance. This raises concerns about the privacy and autonomy of employees and the extent to which they can consent to the use of technology and have control over its use (see also Rathenau Instituut 2020c). If the images are stored and shared, other potential privacy and confidentiality issues arise – at a personal level, but also at the level of organisations (in the case of patented data or processes, for example). (See Stoltz et al. 2017.) Company data policies are crucial for mitigating such risks.

3.6 *Pokémon GO* invasion in The Hague

AR is not only used professionally, but also has numerous applications in the field of entertainment. Augmented reality games are a widespread example. The best known game of this type is *Pokémon GO*, which was created by the American company and Google spin-off Niantic, and launched on the Dutch market in July 2016. The game was a huge success in this country, much like elsewhere in the world. In the first few days after its launch, the game was downloaded more than a million times (NU.nl 2020). In this practical example, we recall the summer of 2016, when *Pokémon GO* caused uproar because of the scale on which it was played in the Kijkduin district of The Hague. We spoke to Rachid Guernaoui, a member of the city council at the time.[10]

***Pokémon GO*: the game**

–*GO* is a game for iOS and Android smartphones. The game uses GPS and AR facets to place virtual creatures, known as Pokémons, in the physical world. The aim of the game is to find, catch and train as many Pokémons as possible, using a digital map. The digital map contains so-called ‘lure modules’, which attract scarce and sought-after Pokémons. A remarkably large number of those lure modules were once to be found in Kijkduin, a district of The Hague with aspirations to becoming a major beach resort. As a result, the district became a magnet for Pokémon players. In the summer of 2016, thousands of mainly young fans visited the Deltaplein in Kijkduin every day.

The municipality was initially pleased with this situation. In a letter to the city council, former mayor of The Hague Jozias van Aartsen wrote: ‘The businesses in Kijkduin benefit from this exceptional form of tourism, and this is beneficial for employment. The business association, the owners of beach clubs and the Beach Resort Kijkduin Foundation were therefore enthusiastic’.[11] Local politician Rachid Guernaoui proposed responding to the attention by erecting a sign to welcome Pokémon hunters and promote local businesses. Guernaoui unveiled the sign, which read ‘Welcome to Kijkduin – Pokémon capital of the Netherlands’, in August 2016 (Teeuwen 2016).

On 9 August 2016, three weeks after the launch of *Pokémon GO*, the city council submitted questions to the mayor about the sign and the side effects of the game, such as pickpocketing, littering and noise pollution. In his reply to the questions, the mayor said that in addition to the benefits, the appearance of crowds also had a downside. ‘In their enthusiasm, many Pokémon hunters traverse areas they are not

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10 Interview conducted on 17 July 2019 in The Hague.

11 Letter from mayor Jozias van Aartsen to the city council, 8 September 2016; reference RIS294835.

supposed to enter. They do not always clear up the mess they make and sometimes urinate where they shouldn't. This causes annoyance, particularly among the residents of Kijkduin'.[12] Residents' associations and dozens of citizens also filed complaints with the municipality. In response, extra public toilets and litter bins were installed and extra cleaning and security staff were hired.

Pokémon hunters also caused a nuisance elsewhere. For example, the Dutch rail network manager ProRail was confronted with people walking along railway lines in search of virtual creatures (ProRail 2016). In India, the presence of Pokémon led to disturbances at religious sites. Similar issues arose at the American Holocaust Memorial Museum in Washington and the Hiroshima Peace Memorial Park in Japan. In each of those cases, the responsible organisations filed complaints with Niantic, requesting it to remove the virtual creatures (Star 2016). Situations like these demonstrate that players of the game may affect not only the quality of life for local residents, but their safety, as well as to violate various standards of behaviour associated with specific locations (consecrated sites, for example).

Business model
It is important to understand how *Pokémon GO* generates revenue. One of the ways that Niantic, the company that created the game, earns money is from so-called 'micro-transactions': purchases of virtual products in the game that give the user an advantage over other participants. Buying a lure module is an example of such a micro-transaction.

Lure modules are also sold to businesses, which use them to attract Pokémon hunters to their shops (see, for example, Zuboff 2019, pp. 309-319). John Hanke, Niantic's founder, told the *Financial Times* that companies 'pay us to be locations within the virtual game board – the premise being that it is an inducement that drives foot traffic' (Bradshaw & Lewis 2016). For the launch of the app in Japan, for example, a major sponsorship deal was sealed with McDonalds. Through virtual lure modules located in its branches, the fast-food chain enticed Pokémon hunters to its 30,000 restaurants. The business model of *Pokémon GO* is therefore similar to that of Google's online advertising market. Companies pay Google 'per click' for every potential customer who visits their site via the search engine. *Pokémon GO* translates this technique from the online advertising world directly to the physical world. Businesses pay Niantic 'per visit' for every customer that enters the shop via its mobile game. Niantic demonstrated for the first time that through AR, digital online business models can also generate income in the physical world. So far, the game has generated more than two billion euros (Tassi 2018).

12 *Ibid.*

Opposition
The municipality of The Hague ultimately hired a law firm to order Niantic to modify the game in such a way as to keep Pokémons and Pokémon hunters away from vulnerable nature reserves. By 'removing the virtual animals from the Westduinpark, Niantic, under the pressure of legal proceedings, finally displayed social responsibility for the physical environment of its game,' the mayor of The Hague later reported to the city council.[13]

Authorities elsewhere chose different approaches. In Lillo in Belgium, the local council decided that the game could no longer be played between ten o'clock in the evening and seven o'clock in the morning (Voorst 2016). Jubise in Belgium even instituted a night-time ban on people assembling (Redactie *De Morgen* 2016). In contrast to the legal proceedings, these responses assigned responsibility for the nuisance to the game's users, rather than to the company that made money off their behaviour. These reactions also make it clear that cases like this constitute a breach of an (unwritten) social contract regarding the use of the public space.

The debate about the use of AR games yet to be resolved. Since 2016, the business model of *Pokémon GO* has been adopted by numerous other AR applications. Furthermore, the game is as popular as ever; it is constantly being developed further, and more than 100 million players worldwide still hunt for Pokémons every month.

3.7 *Mirror Worlds* at The Hague Central Station

The last example in the series concerns our own experiences with the design and testing of the mobile game *Mirror Worlds*, which artist-in-residence Roos Groothuizen, in association with programmer Arran Lyon, devised for the Rathenau Instituut. The purpose of the initiative was to test observations that were made in the course of our research in an artistic manner, and in this way, to acquire new insights into the phenomenon of AR.

***Mirror Worlds* as a provotype**
Mirror Worlds is an online game that can be played by several people. Participants take turns photographing objects they encounter in public space. Other players then have to find those objects and also photograph them. *Mirror Worlds* does not use AR technology, but employs existing objects and persons in the physical

13 Letter from mayor Jozias van Aartsen to the city council, 25 October 2016; reference RIS295331.

environment as game elements. This way, not only the environment but also passers-by and objects are part of the game.

Groothuizen describes the game as a ‘provotype’: a provocative prototype (Gunn et al. 2015). The concept of provotypes is derived from design-oriented research, but provotypes are increasingly applied also in an academic context (Council for Culture 2018). The game’s name, *Mirror Worlds*, refers to the ‘mirroring’ that occurs when reality is presented digitally. The game challenges its players to explore their moral boundaries in a public environment. It confronts them with questions such as: what can (or cannot) acceptably be documented and shared? Which public spaces can (or cannot) be used as a game situation? Which frictions does the use of the game, or AR technology, cause?

To analyse the answers to these questions, we drew up a questionnaire together with Groothuizen and presented it to a group of ten Master’s students at the Royal Academy of Art in The Hague, on 29 January 2020. The students took part in a playtest, conducted in the main hall of Central Station in The Hague: a busy location with a utilitarian function and many passers-by. The students played the game for twenty minutes and then completed the questionnaire. Below, we reflect on our observations of them playing the game, a group interview conducted afterwards, and the responses to the questionnaire.

Boundaries

First and foremost, the students reported enjoying playing *Mirror Worlds*. As the game progressed, the students became increasingly involved in it and chose to take more challenging photos. For example, they took snapshots in increasingly inaccessible locations. In the process, they also increasingly invaded the personal space of other people – for example by focusing on the shoes of passengers or station staff members. At the same time, the players barely noticed that their game, accompanied by uncoordinated rushing around and shouting, could be a source of annoyance for passing travellers. A number of players conceded that this was perhaps true, but said they had not been aware of it because of the hustle and bustle in the station.

In the group discussion afterwards, the players reported that their experience of particular actions are permissible or not, heavily depended on the location of the game. In general, they considered a railway station to be an outstanding location for playing *Mirror Worlds* – precisely because of how busy it is. Doing so would not be acceptable in spaces where people are expected to remain quiet, such as graveyards, libraries or museums. In dangerous environments such as around railway tracks, they felt, it also would not work. While the players claimed that they would personally respect those principles, they added that not everyone is in a position to do so. Children, for example, cannot be expected to be able to judge whether or not an action is to be deemed acceptable for a specific location.

What does going 'too far' entail?

After the playing of the game, a discussion took place concerning the permissibility of particular actions. For example, the participants discussed the legitimacy of photographing conductors and passers-by who did not at that moment know that they were part of a game. They also raised the issue of secretively taking photos, out of concern for the privacy of a subject. Most players felt that photographing a person's face without their consent was going 'too far' – in contrast to a person's shoes or back, for example. In this context, the comment was also made that visibility could lead to social friction – which participants sought to avoid. They did not want to harass passers-by and therefore concealed that they were participating in a game. This suggests that to a certain extent, they tried to consider the generally accepted social standards that apply in public spaces.

The players disagreed about who bears responsibility for the hybrid environment and its rules and norms. Some suggested that the designers of games should be subject to rules, for example in the interest of the protection of privacy, safety, and respect for certain social standards. Those rules could be imposed through government intervention or by means of self-regulation by the sector. Others felt that the responsibility lay with the user. However, they said it would be difficult to formulate rules, because people differ greatly in their perception of right and wrong.

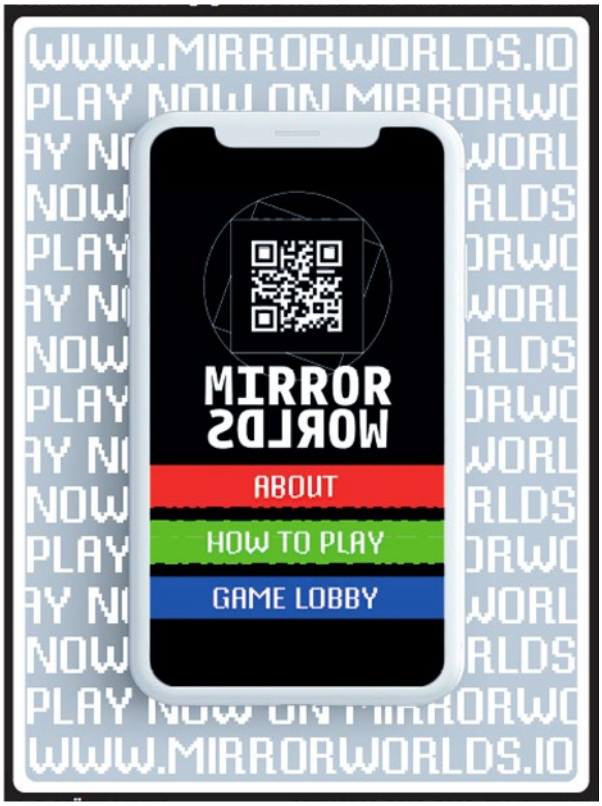

Figure 3.2 *Mirror Worlds* application

Source: Roos Groothuizen

3.8 Reflections

The AR practices described in this chapter illustrate the potential of AR in a range of areas: from health care, via construction and logistics, to entertainment. The examples show that a great many technical and economic challenges need to be overcome and that, in many respects, AR is still in its infancy. The six examples also illustrate the three categories of societal issue that we referred to in chapter 1: data issues, manipulation issues and spatial planning issues. In this section, we summarise the chapter along those themes.

Technical and economic feasibility
AR practices that are still in the pilot phase highlight numerous technological challenges. There is still room for improvement in the battery life and the speed of AR systems. Local safety rules are sometimes incompatible with wearing a headset. A constant challenge is how to reconcile the use of AR with existing practices and (safety) standards. The use of AR in dynamic environments

(physically and socially) is particularly challenging. For example, screens are not yet able to adapt properly to the environment when a user moves outside from indoors. It is still technically difficult to make the complex projections dynamic enough and allow them to be seen by different members of a team with different vantage points. Therefore, the balance of costs and benefits is uncertain for many parties at this point.

Data issues

In the field of neurosurgery, one data management issue is how to deal with the holograms of patients' brains. How can the privacy of patients be guaranteed? Should hospitals store brain holograms themselves, or might they delegate this to private parties? Privacy issues also arise with AR games and with the professional use of headsets by organisations such as distribution centres. Relevant questions include: to what extent may employees be monitored by employers and should employees be asked to give informed consent to the collection of personal data? In the example of deck marking, we saw that the use of cameras can lead to issues relating to the storage of (confidential) data such as camera images.

Manipulation of perception and behaviour

Various practices demonstrate that AR can influence the perception and the behaviour of users in numerous ways. On the one hand, AR can function as a digital prosthesis and enhance people's cognitive capacities. Such forms of human enhancement could have an emancipatory effect. The fact that AR is intuitive contributes to this. AR can make abstract images, which could previously only be interpreted by experts (the two-dimensional MRI scan in health care, the flat technical drawings in construction and deck marking), comprehensible to laypersons. This helps to simplify communication about complex images and tasks. In the healthcare sector, the hologram of a patient's brain can help in the training of young doctors and assist surgeons in preparing for operations and in interacting with patients. In the construction of the Boekelo bridge, AR improved communication and mutual understanding between employees with different specialties. And in deck marking, AR opened up the way for a new division of labour by also enabling non-specialists to position markers on the deck.

On the other hand, AR can be used to influence the behaviour of users, as demonstrated by the example of *Pokémon GO*. Niantic's business model stands or falls on the possibility of influencing foot traffic, i.e. the shopping behaviour of pedestrians with virtual lure modules. Such applications are constantly being developed to make them more attractive and more addictive, so that players will spend more of their time in the game and generate more income for the company.

Spatial planning

We have discussed a number of applications of AR in relatively closed private environments: an operating theatre, the deck of a ship, a building site. In contrast, the mobile game *Pokémon GO* and the game we designed ourselves, *Mirror Worlds*, are used in public space, accessible to everyone. The fact that this is a shared space compels users to consider one another. Depending on the specific space, the applicable standards of decency and statutory rules may vary,. For example, we saw that when *Pokémon GO* was introduced in Kijkduin, the users of AR violated both types of rules. Some people entered a nature reserve and thereby, disrupted public order. We also found that the owner of the game, Niantic, only took social responsibility for desirable use of the public space under pressure from the government.

The students who played the *Mirror Worlds* game said afterwards that they were very conscious of the type of environment in which the game was played, the standards and values that applied there and the people who shared this physical space. They actively sought a balance between the rules of the digital game and the rules of the physical space in which it was played. If AR is going to play an increasingly important role in public space, this raises the question of how users of AR – who experience a hybrid, physical-virtual world with its own standards and values – will share the physical space with other users. Will public space then become fragmented into different AR zones and bubbles?

Intermezzo: future scenarios for AR

As well as devising the *Mirror Worlds* game, Roos Groothuizen, Rathenau Instituut's artist-in-residence and a member of the AR project team, also developed a number of visual future scenarios. The scenarios consider ways in which we might be using AR in the future – more specifically in 2026. They specifically address some of the ethical and societal issues discussed in chapters 3 and 4. They visualise the risks of AR, but in some cases also playfully suggest specific solutions. Some of those solutions are technological in nature, others are more administrative.

The first scenario (figure I.1) depicts a user of the deep-fake application DeepNude (which we discuss in section 4.4 of the next chapter). This app allows the user to virtually 'undress' another person, as it were. The situation outlined here illustrates how AR enables people not only to shape their own hybrid identities, but also manipulate those of others. Groothuizen suggests that we could mitigate this risk with a 'Do Not Locate' register, an (as yet imaginary) variant on the existing Do Not Call register, but for people who do not wish to be the victim of AR modification by others.

In contrast, the second scenario (figure I.2) illustrates in a very tangible way what AR could contribute to the mental well-being of *users* of the technology. Groothuizen imagines an application that allows people to virtually modify their appearance. The program then collects data about plastic surgery practices in their immediate vicinity. In this way, the app presents the manipulated reality as the 'ideal' reality. The scenario evokes the idea that excessive use of AR filters could lead to a distorted self-image. Research has shown that such situations are no longer merely hypothetical (see section 4.3).

The last three scenarios elaborate on experiences with the use of AR in public space. In chapter 3, we showed that games like *Pokémon GO* can be disruptive, both for humans and for nature, when they are played in public places. This raises the question of whether the use of AR should be restricted in one way or another, for example by banning its use in certain locations – by analogy with a ban on smoking a joint in public (see figure I.3). Cities could, for example, establish zones where, in contrast to 'AR-free' zones (figure I.4), the use of AR is permitted or required. In this case, it could be useful to inform citizens of *why* its use is or is not permitted in those locations or between certain hours (figure I.5). This could in turn help to initiate a discussion on what can be regarded as 'good manners' in our shared hybrid world. After all, recent events indicate that what seems evident in the physical world can no longer be taken for granted in the physical-virtual world.

Figure I.1 AR and deep fakes

Source: Roos Groothuizen

Figure I.2 AR and identity

Source: Roos Groothuizen

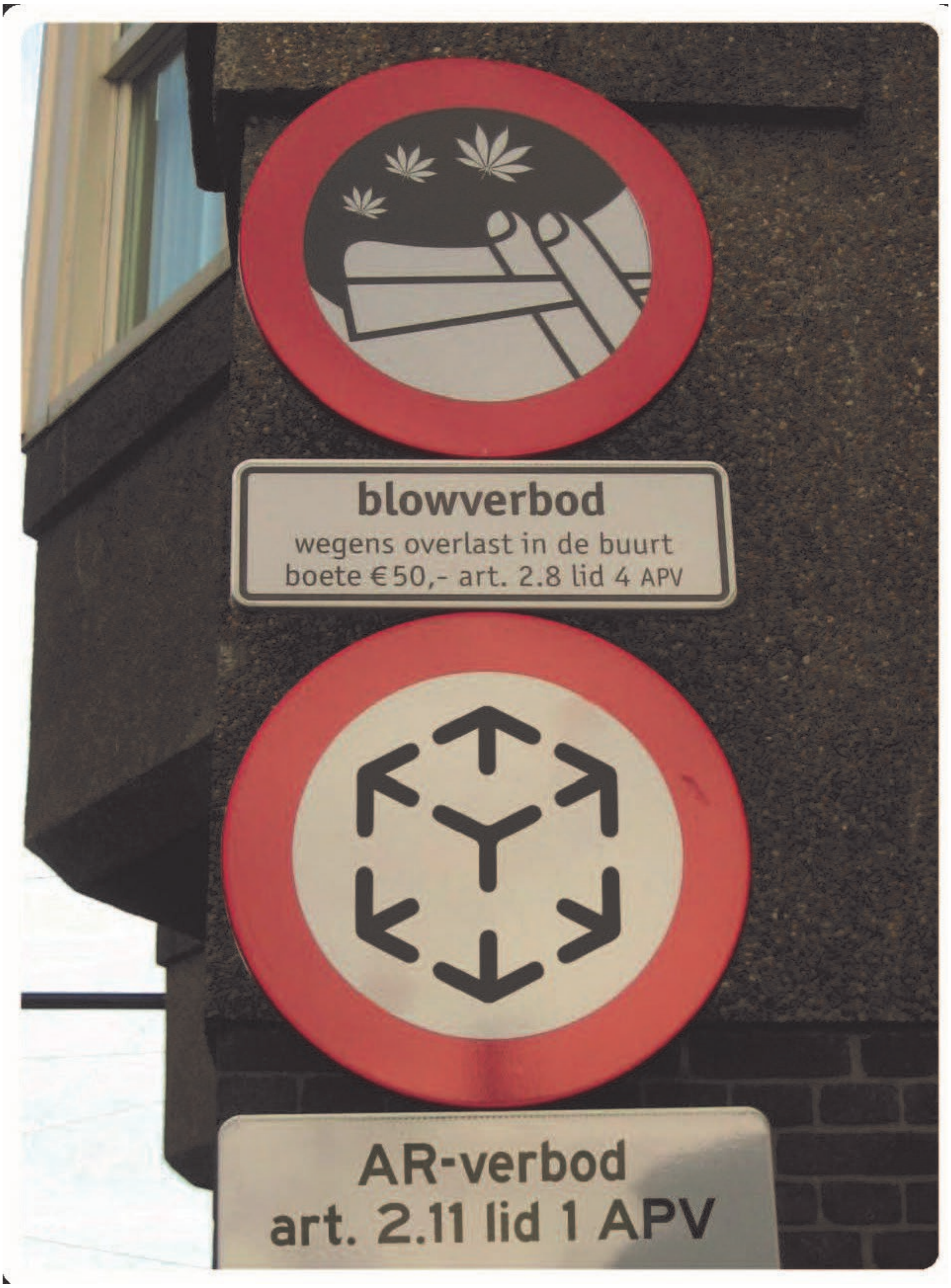

Figure I.3 The use of AR prohibited

Source: Roos Groothuizen

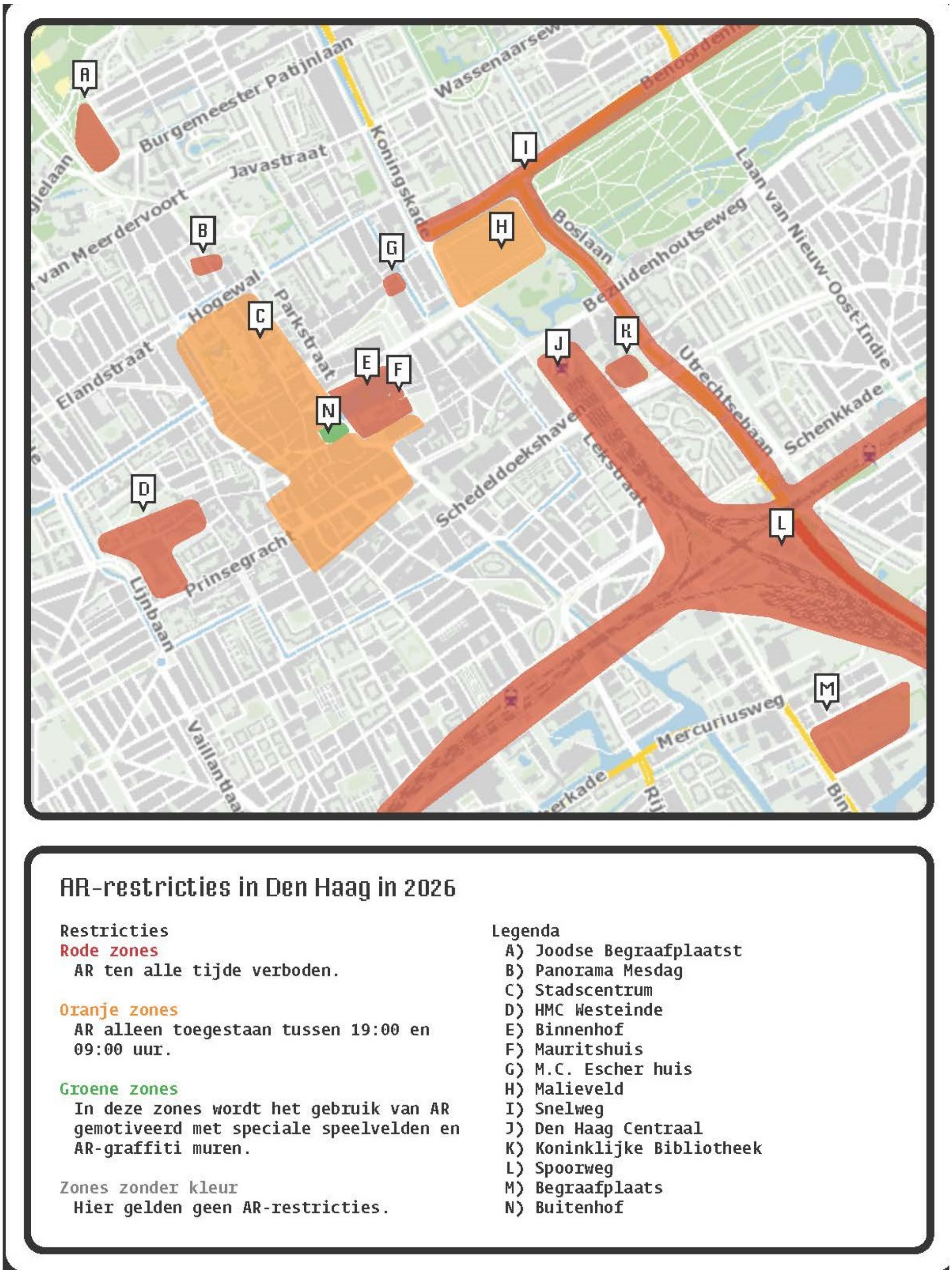

Figure I.4 AR zones and restrictions

Source: Roos Groothuizen

4 AR in the literature: ethical and societal issues

4.1 Introduction

The previous chapter described a range of societal issues relating to existing uses of AR. In this chapter, we explore those and other ethical and societal issues in more depth on the basis of scientific literature. The relevant literature reflects on the current practice of AR, but also considers issues that could come to play a role in relation to AR in the coming years.

Our research shows that although the number of scientific publications on societal and ethical issues raised by AR is increasing, they are still scarce. For this report, therefore, we have also consulted non-scientific sources, such as news reports, articles by journalists and publications from the private sector. For the scientific literature, we focused on the period from 2009 to 2020. We searched for relevant sources in Google Scholar, JStor and Web of Science. In these digital libraries we searched on the primary search term ‘augmented reality’, in combination with at least one of the following terms: ‘ethics’, ‘ethical’, ‘moral’ and ‘morality’. The search yielded 41 articles and conference papers of relevance for this study. They are listed in the bibliography in appendix 1 of this report. The scientific articles were carefully analysed to identify the most relevant issues (see figure 4.1).

Societal issues		
Data	**Manipulation**	**Spatial planning**
Privacy	Physical and mental well-being	Identity formation
Consent and control over AR	Perception of reality	Planning of hybrid space
Data ownership	Dehumanisation	Experience of public space
Information asymmetry	Cognitive freedom	Commercialisation
	Manipulative power of large tech companies	

Figure 4.1 Overview of AR-issues mentioned in the scientific literature

Source: Rathenau Instituut

As mentioned in chapter 1, we distinguish three clusters of societal issues: data issues, perception-control or manipulation issues and spatial planning issues. Data issues arise from the collection and processing of data and cover themes such as privacy and data ownership. Manipulation issues are connected with the manipulation of the cognition, perception and behaviour of AR users. In short, what users perceive, think and do. Spatial planning issues concern the question of what AR means for the design and perception of our spaces, both the hybrid and the physical environment. The impact of each of these issues depends on the context and the type of space in which they arise. In discussing these issues, therefore, where necessary we make a distinction between personal, private and public space.

4.2 Data-related issues

The processing of data for AR raises a number of societal issues. The question of privacy receives particular attention in the literature (see, for example, Acquisti 2014; Kotsios 2015; Kudina & Verbeek 2018). This relates to the collection and processing of personal (often biometric) data of AR users. There are also issues relating to consent, control of technology, ownership of AR data and equality of access to information. We discuss these themes below. It is important to realise that all of these issues affect not only those wearing the AR headset (AR users), but also anyone who enters the field of vision of AR systems. Other questions relating to non-users are what biometric data about them are collected, whether they can decide for themselves whether they will or will not be registered by AR sets, and who owns their data.

Privacy: collection of biometric data

We have described AR systems as data machines, which collect data about the user and the user's physical environment (which also includes other persons). To do this, AR uses advanced sensors, such as cameras for facial and behaviour recognition, smart microphones and sensors, which can register our location, the steps we take, our eye movement and facial expressions, our hand movements and our posture. In chapter 2 we explained how this technology works and how technologies such as facial, behaviour and voice recognition are becoming steadily better at identifying individuals, objects, speech and sound. With powerful cameras, users and non-users can be identified further and further away. For example, there are now commercial applications that can recognise people at a distance of more than fifteen metres (Farfaces, 2020).

These intimate data can be collected, stored and shared without others noticing. According to Kotsios, the registration process in AR is therefore 'completely seamless and surreptitious' (2015, p. 168). AR systems work best if they are always on, so that the most complete possible hybrid environment can be constructed. The device is mounted on the user's head and points in precisely the same direction as the head, making it almost impossible for the subject to know that he or she is being filmed or photographed. The fact that a growing number of these AR systems are operated by voice or gestures makes the registration process even less visible. For example, Google has introduced a wink feature, allowing the user to make photos by winking. Devices are also becoming ever smaller and less visible. AR lenses are now being developed.

Because AR is generally used in a social context, in the public space for example, all of these factors immediately raise a number of privacy issues. This applies in particular to the use of facial and behaviour recognition cameras. Facial recognition technology can be prejudiced, because most AI systems that are used are trained on the basis of databases containing a disproportionate number of photos of Western men with a light skin colour (Buolamwini & Gebru 2018). Consequently, women with a darker skin colour are often incorrectly identified (margins of error of up to 34.7% compared with 0.8% for men with a light skin colour, see *ibid.*). The use of systems of this type by the police could therefore lead to the arrest of the wrong person. In various places, the authorities are discussing a ban on this type of technology. In a number of American cities, for example San Francisco, such a ban has been introduced for the police and other government bodies (see Conger et al. 2019). In 2020, Clearview AI, a company that sells facial recognition software, was sued over the compilation of its facial recognition database. The database has been used frequently by security companies and government agencies. The company had acquired its enormous database (comprising three billion photos) by scraping various social media websites. Because of the uproar, IBM stopped its research into and development of facial recognition technology (see Peters 2020).

Behaviour recognition raises similar issues. Motoric data collected and analysed by the AR system can be combined to produce a unique ‘kinematic fingerprint’, with which individuals can be identified (Kopfstein 2016; Madary & Metzinger 2016). This kinematic profile can also be used for other purposes. The process is referred to as function creep. A dataset that has been collected in a game situation could be sold to security firms to identify people in semi-public spaces with cameras. By linking behavioural data to data from online databases or details of a person’s search history on the internet, information can be gathered about a person’s purchasing behaviour, relationship status, network of friends, political preferences or other private data (cf. Zuboff 2019). The linking of big data in particular makes unique identification of persons possible. The collected dataset can threaten human rights, including privacy. The Rathenau Instituut has previously reported that the current legal frameworks in the field of biometric applications are inadequate (Rathenau Instituut 2015; Rathenau Instituut 2019). The combination of an inadequate legal framework and the widespread use of AR systems with facial recognition brings with it the risk that persons can no longer remain anonymous in the public space, since AR systems register not only the users of these systems, but also non-users.

Consent and control over AR

The development and application of AR in social contexts also raises concerns for a ‘Little-Big-Brother*’* scenario, where not only governments, but also citizens and companies constantly use technology to monitor one another and endeavour to influence each other’s behaviour (Rathenau Instituut 2017b). That not only creates a surveillance society, in which devices such as security cameras monitor individuals, but also a ‘sousveillance’ society, in which everyone can monitor everyone else. The possibility of giving consent to various forms of AR registration is therefore a subject that demands special attention.

Another important ethical issue relating to AR is the degree of control users have over the system. How much control do they have over the functioning of an AR device or application? Many of the questions raised have to be answered separately for each AR application. For example, can a person register or deregister for biometric registration with a specific application? What control does one have over the information that is shared or processed? Is one able to ascertain where, when and who is using data from the application to identify people? Is it possible to switch off particular functionalities or is one entirely at the mercy of the technology? Does one have any say in what data the technology collects, analyses and shares? Issues of this nature apply not only to the private use of AR, but also on the shop floor. Can an employee refuse to use AR or exercise control over which functions are used? And what is the situation in a social context, where non-users do not know that their biometric data is being collected by another person's smart glasses?

Data ownership

Issues of privacy and ownership are interconnected. For example, who owns my image, a recording of my voice or my kinematic fingerprint? Legal provisions state that the context is important in this respect. The rules differ according to whether the recording is made in the public space or a private space. Apart from the context of the environment, the technological context, in other words the type of recording that is made, is also a factor. This is more of an issue with AR than with ordinary recordings, since AR registers numerous data that can be immediately processed, manipulated and shared.

An important question here is whether the wearer of smart glasses or lenses has exclusive rights to data relating to what he observes (Brinkman 2014; Wolf et al. 2015). Google applied for and was granted a patent for technology with which it can be seen what the wearer of a Google Glass is looking at by monitoring eye movements. This means that the company can not only access the image seen by the wearer of the glasses, but can also acquire information about precisely what the wearer is looking at, and when. Data of this type can be very lucrative and useful, for example for profiling and manipulating users. It might seem obvious that what the user sees in the hybrid environment belongs to him – but that is not the case.

Wolf et al. (2015) argue that it is essential to make explicit legal arrangements on this type of issue in hybrid environments, where both users and developers can claim ownership. Those agreements could vary depending on the context. Once the user invests in a hybrid environment, for example by buying AR accessories, avatars or objects, his or her claim might be greater, on condition that the trade in virtual objects is correctly regulated in law. In any case, the creation of hybrid environments calls for clear agreements between developers, governments and users about the rights a person can derive from ownership of virtual objects or elements within a platform. This applies in particular for hybrid environments in public spaces, such as a village square, where the environment serves a public purpose and is used by many people.

McClure raises yet another type of ownership issue, which follows from the fact that AR applications can exhort people to visit physical locations (2017, p. 358). That situation is leading to a growing number of legal actions concerning violations of property rights and destruction of property. The growing popularity of these types of application could lead to more legal conflicts. According to the author, a so-called 'Do-Not-Locate' register could help to exclude specific locations from the use of AR. Roos Groothuizen includes a similar register in one of her scenarios in the Intermezzo prior to this chapter. The register would give local authorities and individual users the power to prohibit property from being manipulated with filters or prevent AR platforms from using the property as a location for its applications. In Germany, members of the public have that option with *Google Maps*. At the moment, however, it is not yet possible to prevent your home from being used for an AR advertising text.

Information asymmetry
AR can enhance the cognitive capacities of its users. As we saw in chapter 3, this can have an uplifting effect. AR enables even non-specialists to understand complex phenomena or tasks, such as a brain tumour or how to position markings on a ship's deck. But AR can also lead to information asymmetry. Smart glasses enable users to gather information about their environment and about other people. Accordingly, AR users could possibly also exercise power over others – often non-users – and do so without their knowledge (Katell 2019, p. 300). This could create a digital divide between users and non-users of AR.

There are also major concerns about the information asymmetry between AR users and the companies that sell these systems and applications. These are often large, multinational IT companies (Zuboff 2019). While people are profiled in numerous ways by these companies, it is difficult for individuals to keep track of all the information that is collected about them, how that information is used online and precisely how they are then influenced by it. Not to mention whether they are capable of responding smartly to the collection and use of their data (Rathenau Instituut 2017a). While individuals are becoming increasingly transparent for large IT companies, the conduct of those companies is becoming increasingly obscure to citizens.

4.3 Manipulation issues

AR is a form of human augmentation that virtually expands our senses and can determine what we experience: what we see, hear and feel. The user's experience depends on which senses are addressed by AR and by the number of the senses that are addressed simultaneously. By monitoring people's eye movements, changes in the pupil size and movements of facial muscles, AR companies can analyse what users are looking at, how long they focus on something and their physical and emotional response. By processing these data and linking them to online databases, the experiences of users (consumers, employees or citizens) can be subtly manipulated.

The use of AR can raise various issues in relation to manipulation. Here we discuss the impact of AR on physical and mental well-being, our perception of reality and our cognitive freedom. We also consider the risk of dehumanisation and of manipulation by large tech companies.

Physical and mental well-being

AR is increasingly used for therapeutic purposes, for example to treat phobias, addictions, eating disorders, stress and chronic pain (Suso-Ribera et al. 2019). This is known as AR exposure therapy, or ARET. Although there has been little research into this application of AR, a number of researchers refer to the positive effects of such realistic virtual experiences. According to Ventura et al. (2018), for example, ARET helps in treating various psychological disorders, because the technology can reproduce and modify experiences in a realistic manner. Using AR, patients can learn to cope with situations that trouble them at their own pace and in their own way in a controlled, virtual environment. For example, a therapist can expose patients to a seemingly realistic spider or lift and thus reassure them that the spider will not do anything to them or that the lift will not break down (*ibid.*). With this method, the therapist does not have to work with the real objects and can also incrementally increase the intensity of the experience. An advantage of AR compared with other digital therapies, such as VR, is that patients retain the feeling of physicality. They remain aware of their own body and the physical environment.

There has been a lot of speculation about the physical benefits of AR. However, they are not evident in every instance. For example, Howe et al. (2016) registered the number of steps taken each day by 1182 users of *Pokémon GO*. The researchers compared the results with the users' behaviour in the weeks before and after they installed the game. Although *Pokémon GO* led to a relatively small increase in the number of steps taken every day after installation, that effect had disappeared after six weeks.

There are also concerns about the physical safety of AR users and others in their vicinity from the use of AR. This applies mainly with respect to the use of AR wearables and AR games, because they demand a lot of attention from the users, can be addictive and are also frequently used in public spaces or in traffic. Players of *Pokémon GO* have been involved in numerous traffic accidents since 2016. At the end of 2019, a website that tracks fatal incidents involving *Pokémon GO* put the number at 21 (Pokémon GO Death Tracker 2019).

Another cause for apprehension is the potential impact of digital filters on a person's self-image. With apps like Snapchat, it is easy to apply filters to selfies and videos. This can prompt users to cultivate an attractive, but distorted, self-image. This incongruity between what one sees in the mirror and the self-image on the smartphone can cause mental problems for users. Rajanala et al. (2020) assert that frequent use of AR filters sometimes leads to body dysmorphic disorder (BDD). People with this mental disorder find an aspect of their appearance ugly and worry constantly about it. There have been a growing number of cases where people have undergone plastic surgery to create the filtered self-image. In that context, a British cosmetic surgeon coined the term 'Snapchat dysmorphia' when some clients started arriving at a consultation for a procedure with filtered Snapchat images of themselves rather than pictures of celebrities as used to be the case (cited in Hunt 2019).

Perception of reality

In their experimental study, Miller et al. (2019) discovered that experiences in AR can have a direct impact on behaviour in the physical environment. For example, test subjects avoided sitting on a chair on which they had just seen a seated virtual person. Furthermore, the presence of a virtual person had practically the same effect on their behaviour as when a real person was standing beside them. 'We've discovered that using AR technology can change where you walk, how you turn your head, how well you do on tasks and how you connect socially with other physical people in the room', said one of the researchers in *Science Daily* (Stanford University 2019).

The chance that the hybrid environment will come to dominate the user's experience is even greater with highly immersive AR applications. This can impair the user's awareness of the differences between the physical and the virtual world. Many AR developers endeavour to create such immersive AR experiences and try to construct the most realistic possible hybrid environment. Their objective is to allow the user to switch seamlessly between the virtual and the physical world and to perform actions in the hybrid world as naturally as possible (Wolf 2016). The ideal is 'true AR', where users do not even notice the modification of their perception of the environment. By analogy with the Turing test (a test of a machine's capacity to display intelligent behaviour that is indistinguishable from that of a human), Sandor et al. (2015) proposed developing a visual test in which people have to try to distinguish between virtual AR objects and physical objects – a so-called Augmented Reality Turing test (ARTT).

A related apprehension is that users, particularly vulnerable individuals, will experience problems if they are no longer able to distinguish between virtual and physical elements. These problems could be physical, a feeling of being unsafe, or mental, such as a derealisation disorder, where those suffering from it experience the familiar environment as alien or unreal. Bailey and Bailenson (2017) observed that it is difficult for people – particularly children – to distinguish between virtual and 'real' experiences. In their study, children, as avatars in VR, swam with whales and afterwards recalled physically doing so.

Dehumanisation

The use of AR on the shop floor brings with it the risk of the dehumanisation and instrumentalisation of humans (Rathenau Instituut 2017b). People are then seen as an instrument that can be directly controlled by the organisation by means of commands that appear directly in their field of vision. Since AR sets are linked almost directly to the employee's senses, they capture a great deal of the worker's attention. That leaves less room for the individual's own cognitive experiences. This risk arises mainly with intensive AR experiences, where the employee's attention is controlled with dynamic layers and gamification techniques. One of the issues that this raises is whether people have a choice in whether to use AR at work, or whether it is a requirement. The use of AR data to monitor employees and to manage or evaluate their performance has prompted concerns about the impairment of employees' autonomy (see also Rathenau Instituut 2020c).

The use of AR in private spaces already raises issues relating to automation and the deployment of personnel. In professional contexts, for example, AR could lead to a new situation where fewer personnel are required to perform the work or to the replacement of existing employees with others who are able to use the technology.

Cognitive liberty

Online platforms play a steadily greater role in determining who gets to see what information online. This information is personalised and varies from one person to another. The result is the creation of filter bubbles (Pariser 2011). Filter bubbles are based on information about the user, such as a person's location, previous clicking behaviour and search history. The fact that the supply of information on the internet is increasingly personalised and monopolised raises questions about the role of large platforms in steering users and our online freedom of choice (Rathenau Instituut 2012).

With AR, the internet moves from the virtual world to the physical world. That shift expands the scope of the filter bubble concept and raises issues regarding the power of digital platforms. AR filter bubbles can provide personalised information in an immersive manner. The total experience can be entirely personalised, the effect being particularly strong with visual or multisensory AR. Two AR users can experience the same room totally differently. One is on a beach and is shown an advertisement of a cool drink, while the other has the illusion of attending a political rally. But in both cases their cognitive liberty is at risk (Wrye 2004).

Manipulative power of large tech companies

According to O'Brolcháin et al. (2016), the manipulation of perception can curtail people's autonomy – their freedom to make independent decisions. The authors fear that the convergence of AR and artificial intelligence could lead to users being nudged by governments or companies to buy particular products or adopt certain opinions. Smart AR filters can respond to a person's emotions. They can do this for instance by using a filter to make it seem that real people smile or frown, depending on the situation. The researchers argue that this type of technology will become even more persuasive and effective if it makes use of data and knowledge about 'the emotional responses of users [acquired] through eye movement trackers and other emotional data capture' (*ibid.*, p. 15).

On the internet, this form of active behavioural manipulation is found mainly in the consumer domain. In *The Age of Surveillance Capitalism,* Zuboff (2019) describes how tech companies, such as Google, Facebook and Microsoft, automatically collect large amounts of information on the internet about people's behaviour, and use that data to predict and modify behaviour. With AR apps and glasses, details of where users are, how long they stay somewhere, what they are looking at and what they buy can be registered. People are monitored over lengthy periods with cookies. They can be steered by presenting them with specific information at specific times. By means of AR, persuasive techniques of this type are penetrating the physical space. Companies can monitor people and steer them in their homes or on the street. Accordingly, AR offers various possibilities for advertisers and data brokers. According to the lawyer Henriksson (2018), the immersive nature of the virtual environment makes this type of virtual advertising even more persuasive and better equipped to influence behaviour.

The fact that the aforementioned tech companies are investing heavily in AR suggests that the development of the technology is driven by a desire to collect data in order to use them to predict behaviour. Zuboff (2019) refers in this context to surveillance capitalism. She observes that steering behaviour is also the best way of predicting behaviour. *Pokémon GO* illustrated very clearly how this business model is monetised in the physical world. Shops try to entice players by offering lure modules, which they buy from Niantic. Companies also pay Niantic for every visit by a customer who enters their shop via *Pokémon GO*. In other words, the players of the game are, often without knowing it, earning money for companies. This is an extreme form of gamification, whereby their behaviour is manipulated, making them part of a large-scale data trading market they are not aware of.

4.4 Issues related to spatial planning

AR is unique because it directly links the virtual environment to the physical spatial environment – including the persons present in it. This raises new issues relating to the creation of our hybrid identity, the planning of our public space and the perception and commercialisation of public and private environments.

Identity formation in the hybrid world
AR devices can help individuals to form their identity (Wolf 2016, p. 129). In the physical domain, people use clothing, jewellery, piercings and tattoos to set themselves apart. In the virtual domain, they use avatars and messages on Pinterest, Facebook or Twitter to express their virtual persona. This is referred to as a digital identity. By analogy, in the case of AR one can speak of a hybrid identity, which is partly physical and partly virtual. In the hybrid domain, virtual elements can be pinned to a person's physical body. In that case, another person sees the user as partly physical and partly virtual – possibly even without being able to make a distinction between the two. There is now a growing AR filter market where AR users can buy new hybrid identities. A Dutch start-up, De Fabrikant, recently even designed a hybrid dress, which was sold for 9,500 dollars (Roberts-Islam 2019).

Some AR applications allow the user to add virtual elements to the appearance of other persons. In such cases, a person's hybrid identity is not determined solely by that person. This can lead to complex social situations, which can be abused, for example in group situations at school (Wolf 2016). One example is the DeepNude app, which removes the clothing from images of women and leaves them looking realistically naked. The app was quickly removed from the internet in response to public uproar. Although the digitally modified naked body is not a 'real' body, removing clothing in this way still has to be regarded as an 'invasion of sexual privacy', according to Citron (quoted in Cole 2018). In the AR scenario presented earlier, artist-in-residence Roos Groothuizen shows a man trying to undress a woman using a DeepNude app. However, the women is registered in the 'Do-not-locate' register, and can thus block being virtually undressed.

Designing the hybrid public space
AR technology has the potential to design our physical environment in various new ways and to give new functions and appearances to existing environments. With the technology, artists can place digital 3D installations in places that are physically inaccessible or where it is prohibited. The game *Real Strike*, for example, promises to transform a wood, a street or an office into a simulated war zone. *Zombies Everywhere!* invites the player to survive an AR apocalypse by fighting against zombies. And *Spec Trek* distributes virtual ghosts around the world and invites users to find and catch them. The possibilities are numerous. One could transform

a museum into an immersive educational environment or launch simulations in the study to prepare for work or difficult situations. The relative rigidity of the physical domain thus becomes flexible and fluid. Spaces are multifunctional and can quickly and easily assume new functions, without the need for physical renovation or new furniture.

AR transforms our experience of a place, and can thus also affect prevailing standards regarding the social use of the space (Katell 2019, p. 294). This can lead to conflicts between AR users and non-users. Users can quite abruptly give new meanings to locations. Consequently, spaces are no longer constructed within a framework of tacit agreement, Katell writes, but become dependent on individual experiences and expectations. A train station can suddenly lose its traditional function and attract hordes of gamers who are there for reasons other than to catch the train. We saw this happening ourselves with Mirror Worlds. But something similar occurred with *Pokémon GO,* which in 2016 drew players to ‘inappropriate’ locations, such as protected nature reserves and cemeteries. As already mentioned, this can lead to social friction, but also create security risks.

Perception of the public space

AR can have a huge impact on the character of our public space. In the futuristic film *Minority Report* (Spielberg, US, 2002), we see people on the street being shown personal advertisements. AR brings this future vision a lot closer. Nor is it inconceivable that in time services will be offered that allow people to only have contact with specific acquaintances. Like with existing social media platforms, the service could block or filter out people the AR user does not wish to see or hear. The aforementioned AR application that filters the homeless out of a street scene is an unpleasant example of this possibility (Halting Problem 2016).

Smart earbuds can also cause such effects as they offer users a constantly changing, personalised audio environment. Accordingly, augmented hearing could have a far-reaching impact on both users’ relationship with their environment and their interaction with other people (inside or outside the environment). Simply using earbuds *de facto* makes people less accessible. In fact, wearing them can actually deter others, because of the signal it sends, intentionally or otherwise, that the user does not wish to be disturbed (Noort 2020). Schnitzler (2014) fears that this individualisation of the perception of the public space will undermine its status as a communal public environment.

Technology correspondent Metz expects that in future there will be various private AR platforms, and thus a variety of separate, collective hybrid spaces (Metz 2017). One refers in that context to a metaverse (a compound of meta and universe). Such a scenario raises numerous issues. Will people become even more divorced from one another in these types of worlds? Will people be able to move from one metaverse to another? Will we start living in private metaverses, or will there also be public metaverses?

Commercialisation of the public, private and personal space
At present, almost all popular AR systems and hybrid environments are developed by large technology companies, which are profit driven. Consequently, there is a serious possibility that the existing and future applications on the market will contribute to the commercialisation of our public space, but also our private and personal space. For example, it is generally prohibited to erect billboards or construct buildings with advertising texts in a nature reserve. Within the hybrid environment, there is no regulation in this respect and there is no recognition yet of the public interest in hybrid public spaces. While many locations in the physical world are public property, the hybrid world is mainly privatised. We saw the effect of that in the case of *Pokémon GO*. In releasing the game, parent company Niantic turned almost the entire world into a game board for a commercial application.

There are many new facets to the commercialisation of the environment through AR. With AR, virtual advertisements can be linked directly to the physical environment in which potential clients find themselves. That applies equally to public spaces, such as public parks and squares, and to private spaces, such as a person’s bedroom or office. Well-known examples are the commercialisation of the home environment through smart speakers with virtual assistants (see Rathenau Instituut 2020b). And, as mentioned earlier, digital commerce does not only involve advertising. AR provides an extensive market platform, in which money is earned by analysing, and making predictions out of personal data, which can be sold to commercial parties wishing to influence the behaviour of users. Consequently, not only the appearance of the environment can be commercialised, but what one observes, what one does, what one says and how one relates to others in the hybrid environment also can gain commercial significance.

4.5 Conclusion

In this chapter we discussed various societal and ethical issues that already exist or which will emerge in the near future with respect to the use of AR. We distinguish data issues, manipulation issues and spatial planning issues.

Data issues arise because AR devices contain numerous sensors to monitor the AR user, other persons and their environment in minute detail in order to construct a realistic hybrid environment. Physical movements, gestures, facial expressions and behaviour are constantly registered with advanced sensors and cameras to present a hybrid world that is as accurate and as interactive as possible. These sensors register a great many environmental data. In the process, they map objects, other users and non-users, which become part of the hybrid environment. These data often include intimate information about users and non-users. With those data, uniquely identifiable data profiles can be produced and shared.

An AR device is also a cognitive prosthesis. It modifies our perception of reality. The AR device steers what we see, hear and feel. AR can influence the physical and mental well-being of users and can also exclude users. Because of the rapid development of the technology, AR offers increasingly powerful immersive experiences. As a result, it is increasingly difficult to make the distinction between virtual and physical, between fake and real. Consequently, parties that develop AR systems, platforms or content can exert considerable influence on what users experience. This can be useful for therapies and learning, but can also lead to situations in which consumers and citizens are digitally manipulated.

Because AR links the digital world directly with the physical environment, it raises new issues in relation to spatial planning. This creates new possibilities to redesign the physical environment and to transform spaces such as railway stations into a classroom or a game environment. Issues arise as, with the use of AR, the generally commercialised digital world with its cookies and trackers seeps into spaces and habitats that used to be entirely physical and non-commercial.

In the final chapter, we discuss how AR could be developed and applied in a socially responsible manner. We do this by formulating design rules for a liveable hybrid environment on the basis of the societal issues that have been identified in this chapter.

5 Eleven design rules for a liveable hybrid world

5.1 Introduction

How can AR be developed and applied in a socially responsible manner? In this concluding chapter we address the main question in this report on the basis of the findings from our study. In chapter 2 we discussed how AR works and some visions for the future of AR. Chapter 3 described how AR is currently embedding itself in society. With an evaluation of a number of practical applications of AR, we also identified a variety of societal and ethical issues raised by AR. Chapter 4 reflected on three types of issue that have been identified in the scientific literature: data issues, manipulation issues and spatial planning issues. In this chapter we formulate eleven design rules for a liveable hybrid world.

These design rules should form the point of departure for the drafting of government policy. They call for action by various government actors, which we specify individually below. But addressing the issues raised is not a task for the government alone. Tackling social challenges calls for collective action (cf. Rathenau Instituut 2018b). The rules are therefore also intended to initiate public debate between politicians and businesses, knowledge institutes, social institutions and the general public. In our opinion, that debate must be conducted without delay.

5.2 AR as a new environment

Our study shows that AR could radically change the world we live in. AR devices modify our perception of the world and therefore herald a new phase in the information society in which we literally look at the world *through* the internet. The technology can act as a surveillance technology that meticulously monitors what is happening in our living rooms, in our work places and on the street. Based on this collected data, AR systems construct hybrid environments which consist of physical and virtual elements, such as navigation arrows, facial filters, virtual buildings or monsters. Those virtual layers are directly linked to the physical environment. With smartphones and headsets, AR users can experience the hybrid world and perform actions in it.

AR has left the realm of science fiction and is already being successfully applied. We discussed AR products that have already proved their value, such as products used to position marks on the decks of merchant vessels for the loading of cargoes and devices for vision picking in distribution centres. AR is already frequently used to design products, to provide education, as a therapeutic instrument or as a training device for defence forces. For example, the American army has already ordered more than 100,000 AR headsets (Brustein 2018). Many applications are still in the pilot phase. The described cases on the use of AR for brain surgery and AR technologies in the construction of the Boekelo bridge are examples of that.

In the consumer domain, the applications are more massive. Smartphone applications such as *Pokémon GO*, Snapchat and TikTok have millions of users in the Netherlands alone. Smart earbuds and virtual assistants are further examples of popular AR applications that are increasingly prevalent on the street and in the home. Google Glass, which was launched in 2014 but taken off the market again a year later, has been resurrected and the smart glasses are now being produced again. Besides Google, Zeiss, Microsoft, Snap, Facebook and Apple are also developing wearables for consumers. The start-up Mojo Vision even hopes to be selling smart contact lenses within three years (Kastrenakes & Carman 2020).

It is difficult to predict how and how quickly AR will develop in the coming years. In chapter 2 we sketched the visions of a number of techno-utopian thinkers for the future of AR which are guiding contemporary efforts in this field. In their view, AR will soon be as mainstream as the smartphone and people will be using the technology all the time. In the process, the distinction between the physical world and the virtual layers superimposed on it will gradually blur (true AR). There is a wide gap between this future vision and existing AR technology. It is also uncertain whether the consumer will continue to embrace AR and in what forms its use will win acceptance in society and the market.

Nevertheless, we have to take the vision seriously because large companies are investing heavily in bringing it about. American and Chinese tech giants already employ many thousands of AR/VR employees, invest billions in AR annually and apply for thousands of patents every year. Tech companies therefore see AR as an important element of their future business model and are making huge capital investments to build the hybrid world of the future. They are doing so according to their own insights and in their own private interests. That is what happened with the internet and the danger is that it will now happen again with the hybrid world. That brings us to the first design principle for a liveable hybrid world.

Design rule 1:
Make a joint effort to create responsible AR

It is crucial that the hybrid world is not designed and constructed exclusively by (large) tech companies according to their own private interests. Politics and society must lead the way in designing a liveable hybrid world based on the public interest. The Rathenau Instituut stated earlier that there is a lack of public and political debate in the Netherlands and elsewhere about the desired role of immersive technologies such as AR (Rathenau Instituut 2018b, 2019). We see public discussion as an essential ingredient for increasing political and public awareness about the social significance of this technology. Greater awareness could ensure that we identify outstanding knowledge gaps, essential normative and regulatory frameworks and possibilities for a more inclusive manner of innovation. As in the case of artificial intelligence (AI), the social embedding of AR should receive more public and political attention in the coming years. The discussion should not be too one-sided.

5.3 Data-related issues

AR devices are surveillance machines that use sensors to collect numerous data about the AR user, non-users and the physical environment. This can only be done in a socially responsible manner if the privacy of the AR user and the anonymity of non-users is guaranteed in the process.

Design rule 2: Guarantee the privacy of AR users

Because people's personal privacy should be protected and people have the right to be left in peace, it is important to protect the privacy of AR users. The Rathenau Instituut has observed on previous occasions that the current legal frameworks relating to biometric applications, like those used in AR devices, are inadequate (Rathenau Instituut 2015; 2020). Under the current legislation (such as the GDPR), privacy ought to be a guiding principle in the design of IT systems. Privacy-by-design is a method by which AR devices can and should be designed in such a way as to minimise the use of sensor data, automatically anonymise data and properly safeguard data.

Design rule 3: Guarantee the anonymity and privacy of non-users

The use of AR glasses with cameras can threaten people's anonymity everywhere. Biometric technologies pose a particular threat in that respect. AR glasses with facial recognition enable their users to identify other people. That was one of the main reasons for the public uproar about Google Glass. Various cafés prohibited its use. AR devices with emotion recognition enable users to acquire information about a person's mental state. Furthermore, the platforms and applications on AR systems can collect data and share them with third parties. Guaranteeing the anonymity and privacy of citizens is an important design principle for the public space (cf. Hof & Est 2011, p. 133).

The Rathenau Instituut has previously advocated giving citizens the right not to be covertly monitored or influenced, through the use of biometric applications for example (Rathenau Instituut 2017a). The Dutch government has acknowledged that this right is already inherent in Article 10 of the Constitution and Article 8 of the European Convention on Human Rights (ECHR). In light of that, the legislature should decide whether the use of biometric applications in the public space should be permitted in Dutch society. Given the risks to society, a ban on the use of biometric applications in the public space, temporary or otherwise, is the most logical solution (Rathenau Instituut 2020a).

Necessary action*: Until rules are adopted at EU level, the Dutch government should impose a moratorium on the use of AR applications in the public space with which citizens can be uniquely identified through biometrics.*

Design rule 4: Clarify issues of both physical and virtual ownership in the hybrid world

In 2019 the Rathenau Instituut called on the government to establish regulatory frameworks for the embedding of VR (Rathenau Instituut 2019). Members of parliament Van der Staaij and Van de Graaf submitted a motion calling on the Minister for Legal Protection to adopt those recommendations (Parliamentary Documents II 2019-2020, 35 300 VI, no. 73). The motion was adopted by a large majority in the House of Representatives. The minister has therefore asked the Ministry of Justice and Security's Research and Documentation Centre (WODC) to investigate the adequacy of the existing rules and regulations relating to VR, AR and mixed reality (Parliamentary Documents II 2019-2020, 26 643, no. 689).

In the case of AR, legal frameworks need to be drawn up to cover both the impact of AR on existing ownership and ownership of AR elements, such as virtual objects and avatars. AR applications can lead to violations of property rights or damage to private property because they entice people to specific locations. Physical properties, like someone's house or car, can also be digitally modified or tarnished in the hybrid world. A possible solution might be a 'Do not locate' register, by which a local authority or individual user can indicate that their property may not be used for AR applications.

The second essential category of ownership regulation concerns the grey area of virtual or hybrid objects. The concept of ownership in the hybrid environment is not clear at the moment. The relationship between virtual elements and the platforms on which they appear is another source of uncertainty. A question that arises with AR is whether the user has exclusive rights to his or her own perception and kinematic profile. At present, companies collect such data via AR and, for example, monitor facial and eye movements, which enables them to see what users are observing. Data of this type are highly lucrative because they can be sold to parties that wish to profile and influence users. It is essential to formulate explicit legal provisions on this type of data.

Necessary action: *The Ministry of Justice and Security should clarify the legal frameworks concerning ownership of virtual objects, particularly in relation to the ownership of humans, including their body.*

5.4 Manipulation issues

We classify an AR system as a digital prosthesis that can expand people's cognitive and sensory capacities. For example, AR can provide users with additional information about the perceptible and non-perceptible world, distort the perception of reality and facilitate communication between people. For this to be done in a socially responsible manner, the following design rules should be followed.

Design rule 5: Protect the mental and physical health of AR users

AR-environments can enable people to learn to deal with various social situations in a safe and controlled manner. Accordingly, AR can accelerate and reduce the cost of learning processes. AR therapy could also help in treating certain mental disorders. Compared with other cyber therapies, such as digital therapy and VR, research and development in relation to therapies based on AR is still very new. Consequently, not enough is known about the effects and risks associated with the use of the technology in therapeutic situations, in particular on a long-term. Further scientific research is therefore needed in this field.

Because AR directly links the physical and virtual and AR systems produce increasingly powerful simulations, it will eventually become more difficult for AR users to distinguish between fact and fiction. Apps such as Snapchat have filters that enable people to create an idealised digital self-image. Frequent use of AR filters could lead to addiction, a distorted self-image and sometimes even to body dysmorphic disorder (BDD). In other words, as well as its positive effects, more research is also needed into the negative effects of AR on our mental and physical health.

In light of the above, there is a need for scientific reflection on and public discussion of the social significance of AR as a technology that comes between us and reality and which mixes reality with fiction. From the perspective of ‘digital literacy’ – the collection of competencies that people need to contribute to our digitalizing society – it is important for people to learn how to deal with the phenomenon of augmented reality in a healthy and responsible manner.

Necessary action*: The Ministry of Health, Welfare and Sport should encourage research and public debate on the health effects of AR. The Ministry of Education, Culture and Science should ensure that coping with AR is covered in the policy on digital literacy.*

Design rule 6: Strengthen human capacities in a fair and dignified manner

AR can enhance people’s cognitive capacities in various ways. Some of our cases, such as the Boekelo bridge, deck marking, and neuro-surgery case, clearly illustrate that. Those cases involved complex phenomena and tasks that can now, by using AR-technology, be understood and performed by others than experts alone.

However, the opposite is also possible. If it is not used properly, AR could degrade human labour to robotic work, whereby the technology determines precisely when the employee has to perform specific actions. That is a prelude to deskilling, instrumentalisation of people and dehumanisation.

In the long term, AR will possibly become a normal part of life, although the place that AR will ultimately occupy in human life is difficult to predict. Twenty years ago, few people could imagine that many of us would now be walking around with a smartphone in our pocket. We therefore have to start asking ourselves now whether everyone will benefit proportionately from the new opportunities created by AR. There is a risk of a new digital divide emerging.

Design rule 7: Protect people’s cognitive autonomy

For some time now, freedom of choice on the internet has been under pressure because of an increasing trend towards personalisation and monopolisation of the information provision (Rathenau Instituut 2012). The issue of fake news and disinformation, and their relationship to freedom of expression and democracy, has been a hot topic since the Cambridge Analytica scandal in 2018 (cf. Rathenau

Instituut 2018a). With AR, it is not only the supply of information that can be personalised, but also the perception and experience of reality. Broader than fake news, AR is therefore about a fake reality and the question of who determines what reality the user experiences. With AR, everything we see, hear or feel can be 'fake'. Accordingly, the concept of the 'filter bubble' – where algorithms personalise our search for information on the internet – could also acquire far greater significance with AR. The algorithms used for AR determine how our immediate sensory experience of reality is filtered and pre-programmed. Ensuring that AR enhances people's cognitive autonomy, or at least does not harm it, is therefore one of the biggest challenges of the AR era.

There are also limits to cognitive autonomy. For example, using AR to undress other people digitally or to algorithmically filter homeless people out of the field of view of the AR user are indecent practices. These types of behaviour can be seen as forms of social discrimination or even digital dehumanisation. This type of filtering also has political relevance, because a world in which homeless people are rendered invisible with filters is one in which 'the political importance of homelessness is low' (Susskind 2018, p. 150). The limits of cognitive autonomy are currently determined by the parties that produce AR hardware, software and platforms. In this report we call for wider participation in this production process and for the formulation of standards and rules for the hybrid world based on a social perspective.

Necessary action: *The government should encourage research and debate into social standards and values (social etiquette) in the hybrid world.*

Design rule 8: Create fair power relationships in the hybrid world

This study shows that many companies, large and small, regard AR as an attractive technology to develop and invest in. We focus here mainly on the role of large American and Chinese tech companies, such as Google, Microsoft, Facebook, Bytedance and Huawei. These companies dominate the current internet economy and are icons of surveillance capitalism, which is characterised by large-scale monitoring and influencing of the behaviour of consumers. There is an enormous information asymmetry between these internet companies and consumers, but also other companies (cf. Rathenau Instituut 2017; Nemitz 2018). These multinationals see AR as a key element of their future business model. We should not allow the now skewed power relationships on the internet – between companies and between companies and users – to also determine relationships in the field of AR. In an earlier study concerning VR, the Rathenau Instituut called for protection of consumers in the virtual world (Rathenau Instituut 2019). The same applies for the hybrid world. People give away, often unwittingly, their most intimate data, making them vulnerable to market parties. Consumers need to be informed about their vulnerable position in this new market-dominated environment.

Necessary action: *The Ministry of Economic Affairs should clarify how the government will guarantee fair relationships between companies and between companies and users in the field of AR.*

5.5 Issues related to spatial planning

AR creates a hybrid environment. Because of the impact that AR can have on the societal and cultural use of the virtual and physical worlds, the technology raises social and political issues. How do we interact with one another in this hybrid space? How public is the hybrid environment? Who decides on its design? In this section we zoom in on three issues that are raised by the hybridisation of various public, personal and private spaces.

Design rule 9: Give citizens control over their physical-virtual identity

With AR, virtual layers can be superimposed over the physical reality – and thus over the individual's personal, most intimate, space. People can use digital filters to create their own hybrid identity, but also to do something similar to the identities of others.

To ensure that people retain control over their physical-virtual identity, there has to be certainty about the precise meaning of the right to physical integrity in the context of AR. That right is laid down in Article 11 of the Dutch Constitution ('Inviolability of the person') and is intended to protect people against unwanted physical (medical) interventions on their body. In the age of AR, it is important to provide legal certainty that people can be protected against unwanted digital interventions on their body, and how that protection will be provided.

One of the questions that arises in that context is to what extent informed consent is required to add a virtual layer to a person. What is or is not permitted in that respect? Should apps like DeepNude, with which a person can be digitally undressed, be permitted? Are people allowed to digitally filter other people out of their field of view? And to what extent should people be free to allow virtual commercials from companies in their personal hybrid space?

Necessary action: *The Ministry of Justice and Security should clarify the right to physical integrity in the context of AR.*

Design rule 10: Create public spaces in the hybrid world

Public space is public property and is in principle accessible to everyone. Pleasant public spaces help to create a good living environment and lays the basis for the development of citizens and their relationship with each other. However, there is far less recognition and pursuit of the public interest in digital and hybrid public spaces. Since the 1990s, there have been advocates who plea for government action to guarantee the public, open and democratic nature of the internet. Despite their appeals, the internet is now controlled mainly by large tech companies. They have commercialised the internet in order to earn money from data. While many locations in the physical world are public property, the virtual world is heavily privatised.

With AR, the digital domain colonises the physical world, and with it the communal public space. As a result, the public character of the public sphere could come under pressure in two interconnected ways. In the first place, AR could lead to the commercialisation of every physical space – including public spaces such as nature reserves, beaches and squares. We have seen how the company Niantic appropriated public space with the game *Pokémon GO*.

Secondly, the experience of public space could come to be digitally personalised through AR. Because AR can further personalise the perception of reality, there is a risk that the notion of a public sphere rooted in common experience will disappear. This process of individualisation is already underway through the use of smartphones, smart earbuds and the use of AR filters. In the long run, this trend could increase and even lead to a situation in which various AR platforms each create, own and manage their own exclusive metaverse, or collective physical-virtual space (Metz 2017). Such exclusive and commercialised hybrid, physical-virtual public space are undesirable. To guarantee the liveability of the hybrid world, the government must endeavour to safeguard its public character in the long term. The government should investigate what is required to accomplish that. One question that needs to be answered is whether a public and open source AR platform should be developed. Since the world does not end at the Dutch borders, there could be an important task for the European Commission in that regard. This issue is closely connected to the current discussion about European digital sovereignty (EPRS 2020).

Necessary action: *The government should investigate how the public character of the hybrid public space can be safeguarded in the long term.*

Design rule 11: Design the hybrid environment in a socially responsible manner

The Netherlands considers it important to take account of numerous public and private interests in designing the physical environment. AR raises the question of how the physical-virtual hybrid world can be designed in a socially responsible manner. We often treat our physical environment with care. For example, municipalities have committees to advise on aesthetics and heritage, whose task is to verify that building plans are consistent with the public interest of the typical character of neighbourhoods, districts and regions. What requirements should be stipulated for the quality of the hybrid environment? A specific issue in relation to spatial planning is deciding on those environments in which particular forms of AR should or should not be permitted. We have seen that AR games can clash with the legal and social rules that apply at particular locations, for example in a nature reserve or a cemetery. AR can also create security risks. The use of *Pokémon GO* at hazardous locations has led to fatal accidents, for example. One of Roos Groothuizen's AR scenarios addresses this issue with signposts and maps showing where AR is forbidden or where people are actually encouraged to use AR (see figure 1.3).

Because the use of AR will influence the use of public space in a variety of ways, it is important for the government to explore how the hybrid physical-virtual environment can be designed in a socially responsible manner.

Necessary action: *The government should explore how the hybrid environment can be designed in a socially responsible manner.*

5.6 Joint search for rules for AR

With the rise of the internet in the 1990s, many in society were very hopeful that it would help to create a new digital public space that would increase democratisation and emancipation in the world. In the last few decades, the internet has mainly become a commercial zone dominated by large internet companies. Customs and behaviour on the internet are largely determined by the rules of surveillance capitalism.

With the emergence of AR, there is far too little reflection on and discussion of the future of the hybrid, physical-virtual world. The development of the technology, the necessary infrastructure and the design of hybrid spaces is dominated almost entirely by the multinational companies that have shaped the internet. That guarantees a commercialised hybrid environment in which personal data are a valuable commodity and are collected without the knowledge of the data subjects. It is important for politics and the public to involve themselves in this development. There is a lot at stake with AR – our most intimate data as well as our perception of reality. From the perspective of the public interest, leaving the development of AR entirely to the market would be irresponsible.

From a democratic perspective, it is essential that the design of our current and future hybrid environment is guided by public values. If we want to fashion a liveable hybrid world that is democratic, we have to invest in social innovation. We need to find a common language to talk about this new world, the social etiquette there and relevant economic and legal rules. We need to do this together, which means with the general public, knowledge institutes, civil-society organisations and businesses.

Citizens should be involved, because they will be living in the hybrid worlds of the future and therefore have a great interest in the quality of life in those worlds. Playing an active role in designing hybrid worlds calls for technological citizenship (Est 2016). For their part, knowledge institutes can clarify the challenges posed by new technologies, and identify solutions. Civil-society organisations can initiate public and political debate about AR and keep the public informed, but also place their (individual) interests in a broader (social) perspective. And since businesses play a key role in designing and marketing hybrid worlds, it is crucial that they also accept their social responsibility. However, the government must propel and facilitate the search for this new language, etiquette and rules.

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Appendix: Sources for desk research into ethical and societal issues

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