Technical University of Munich

Strategic and International Management

Impact of Virtual, Mixed, and Augmented Reality on Industries

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Introduction

Explanatory Notes (1/2)

In the recent past, Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR) have attracted considerable public attention: Facebook bought Oculus, a company producing head-mounted VR displays, for USD 2 billion (Wagner, 2016); On July 6, 2016, *Nintendo's Pokémon Go* AR game was launched and reached 50 million downloads within 19 days (Smith, C., 2017); In 2016, Microsoft's HoloLens was launched and showed the world how the future of MR smart-glasses might look like.

While VR has been popular with the video game industry, savvy entrepreneurs and major corporations start to create value from the multitude of VR and AR & MR applications for the consumer and the commercial market. Market expectations are high, which is also reflected in predictions of major research institutions: *Deutsche Bank Research* predicts that the global market for AR will grow from EUR 500 million in 2015 to EUR 7.5 billion by 2020 (Heng, 2015). *Goldman Sachs* predicts in the base case that the global market for VR and AR will grow to USD 80 billion by 2025. In the case of accelerated uptake, they estimate the global market for VR and AR to reach USD 182 billion by 2025 (Goldman Sachs, 2016). The aim of this research is to identify industries, in which VR and AR & MR applications have a radical impact and potentially a disruptive effect.

To analyze VR, AR & MR applications, we need to look at the VR, AR & MR hardware first. Hardware and Applications are complementary innovations. Sufficient technological readiness of the hardware is a precondition to application diffusion. While there is a broad range of hardware devices to display VR, AR & MR, this research focusses on devices that are either handheld or head-mounted. Through expert interviews, we assessed the technological readiness of the hardware available on the market today.

Our key findings are:

- Current technological readiness of VR head-mounted-displays (HMD) is insufficient (e.g. mobility, recording of facial expressions, resolution) but viable devices might enter the market before 2020.
- Most of today's AR HMDs superimpose the digital content in 2D at a fixed distance, which results in poor user ergonomics. These HMDs are likely to be replaced by AR & MR HMDs with 3D capabilities. Viable AR & MR HMDs might enter the market before 2030. Meanwhile, handheld AR (smartphone-, tablet-based) will remain the dominant hardware platform for AR & MR.

After the analysis of the hardware, we predict that VR as well as AR & MR applications will diffuse in two phases between 2020-2030 and 2030-2040. In total, we identified 30 relevant applications: 14 VR applications and 16 AR & MR applications. These applications are categorized into 16 applications relevant to the consumer market and 14 applications for the commercial market. All applications are introduced in Appendix D of the slide deck.

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Introduction

Explanatory Notes (2/2)

Based on 41 industries, derived from the United Nations International Standard Industrial Classification Scheme (ISIC), we measured the impact of VR, AR & MR on each industry. Through matching the applications with industries, we identified which applications represent a major departure from existing practices in the respective industry. These radical innovations might trigger a process of industrial change. Our key propositions are as follows:

Communication and IT Service Industry:
- Social VR will establish itself on the market between 2020 and 2030
- Social VR will substitute parts of conventional online dating experiences between 2020 and 2030

Music Industry:
- VR Experiences will potentially disrupt the music industry between 2020 and 2030

Education Industry:
- Distance education institutions will win over market shares from bricks-and-mortar education institutions between 2020 and 2030

Retail Industry:
- AR Configurators will increase online furniture sales between 2020 and 2030
- VR Online Shops will emerge as an additional sales channel between 2020 and 2030
- VR Online Shops will change the online fashion sales process between 2030 and 2040

Real Estate Industry:
- VR-enabled sales processes will become industry standard for new building projects between 2020 and 2030

Manufacturing Industry:
- VR-enabled design and planning processes will reduce costs and increase productivity between 2020 and 2030
- Augmented facilities and augmented manuals will increase the productivity of shop floor workers between 2020 and 2030

Automotive Aftermarket:
- Car workshops will increase their productivity between 2030 and 2040

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Hardware and Applications

Explanatory Notes (1/1)

The section “Hardware and Applications” introduces VR, AR & MR technologies. In fact, VR, AR & MR technologies are not new: Widespread research into VR, AR & MR started in the 1990s. While Cave Automatic Virtual Environments (CAVE) were the first major VR hardware solution, the concept of AR was formulated in 1991 (Caudell & Mizell, 1991; Cruz-Neira, Sandin, DeFanti, Kenyon, and Hart, 1992).

[Slide 6] Based on the Reality-Virtuality Continuum introduced by Milgram, Takemura, Utsumi, and Kishino (1995), we argue that VR, AR & MR can be assigned to a continuum that ranges from the real environment to a completely virtual environment: On a hardware level, most AR devices superimpose digital 2D information at a fixed distance on the real environment. MR devices merge digital 3D objects with the real environment. VR devices display completely virtual environments. While the delineation between VR and AR/MR is clear, the distinction between AR & MR is less obvious: On the one hand, both technologies power about the same set of applications. On the other hand, MR is the technological continuation of AR: While in AR the real and digital information is distinguishable, the transition is more fluent in MR. This has led to a situation, where the terms “Augmented Reality” and “Mixed Reality” are being used interchangeably. In this research we will analyze AR & MR applications which extend humans’ perception of the real environment and VR applications which allow humans to perceive virtual environments.

[Slide 7] While there is a broad range of hardware devices to display VR, AR & MR, this research focusses on devices that are either handheld or head-mounted. Current AR devices can be distinguished by Handheld AR and AR HMDs. Handheld AR describes smartphones or tablet computers that superimpose 2D images on the video stream of the camera. AR HMDs are donned like a pair of conventional glasses. They superimpose digital content directly on the user’s field-of-view. As AR HMDs are mainly used for commercial/manufacturing use cases requiring mobility, devices are often untethered and mostly self-contained (not hosted on non-mobile external hardware). As MR HMDs had been introduced to the market only recently, there are only few devices available today. In general, MR HMDs can superimpose 2D images just like AR HMDs. Most importantly, however, they can merge 3D objects with the environment. Current VR devices can be distinguished by Mobile VR HMDs and Tethered VR HMDs. Current Mobile VR HMDs essentially consist of a smartphone which is inserted into a container with integrated optical lenses. The VR experience is hosted on the smartphone. Tethered VR HMDs need to be connected to a high-end computer which performs the graphical processing and hosts the VR experience. However, Untethered VR HMDs are slated for introduction on the market.

[Slide 8] In general, VR, AR & MR applications can be distinguished by the target market and by the type of information exchange that is happening. To classify the target market, we identify the primary users of the application: Applications for the consumer market and applications for the commercial market. Even though, some applications can be used on both markets, applications were matched to the market that primarily benefits from their use. To classify the type of information exchange, we identify the primary partners in the information exchange. When using Information and Communication Technology, the user exchanges information with: (1) an underlying backend software system which will be referred to as Interaction with a Software System (ISS) or (2) with other humans through the use of computers which will be referred to as Computer Mediated Communication (CMC).

[Slide 9,10] In total, we identified 16 consumer and 14 commercial VR, AR & MR applications. A description of all applications can be found in Appendix A of the slide deck.

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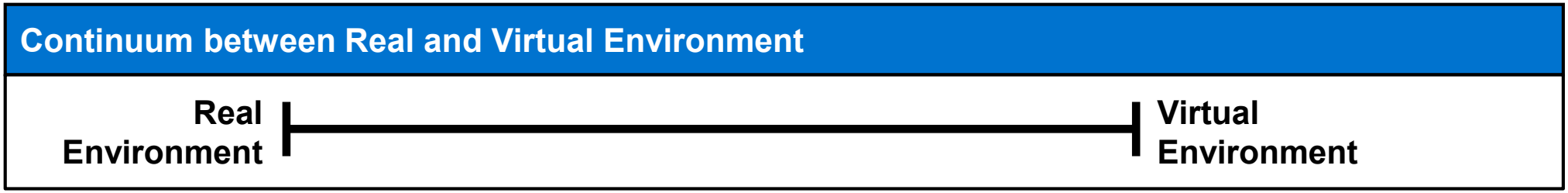
Augmented, Mixed, and Virtual Reality are on a continuum between the real environment and the virtual environment

VR/AR/MR on the Continuum between Real and Virtual Environment



Hardware Level	Augmented Reality (AR)	Mixed Reality (MR)	Virtual Reality (VR)
Core Function	Superimposes information or objects onto the real environment	Real and virtual environments are merged naturally	Displays virtual environments

Application Level	AR/MR Applications	VR Applications
Core Function	Extend humans' perception of the real environment through superimposing digital information	Allow humans to perceive completely virtual environments

Source. Adapted from Milgram, Takemura, Utsumi, and Kishino (1995).

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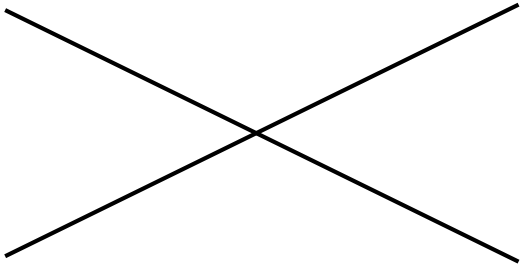
There is a range of entry-level and high-end devices to display Augmented, Mixed, and Virtual Reality

Current VR/AR/MR Hardware Devices

	Current AR devices	Current MR devices	Current VR devices
Entry-Level Devices			
	Handheld AR Smartphone or tablet based AR that superimposes 2D images on the video stream of the camera		Mobile VR HMD A smartphone is inserted into a VR container with integrated optical lenses.
High-End Devices			
	AR HMD AR headsets superimpose 2D images on the user's field-of-view	MR HMD Apart from 2D images, 3D objects can be merged with the environment	Tethered VR HMD Needs to be connected to a high-end computer which hosts the processing

Note. HMD = Head-Mounted-Display. Source. Top left: Baumann (2016). Top right: Krizsak (2017). Bottom left: Brandsynario (2018). Bottom middle: Microsoft (2016a). Bottom right: Painter (2017).

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VR/AR/MR applications can be distinguished by the target market and by the type of information exchange

Categorizing VR/AR/MR Applications

Participants from which market use the application?

Market Economy View

- Consumer Market: The application is primarily used by ***end-consumers***
- Commercial Market: The application is primarily used by ***employees*** to improve corporate processes

Who are the partners in the information exchange?

Information Science View

- Computer Mediated Communication (**CMC**): Information exchange ***between humans*** through the use of computers
- Interaction with a Software System (**ISS**): Human information exchange ***with a software system***

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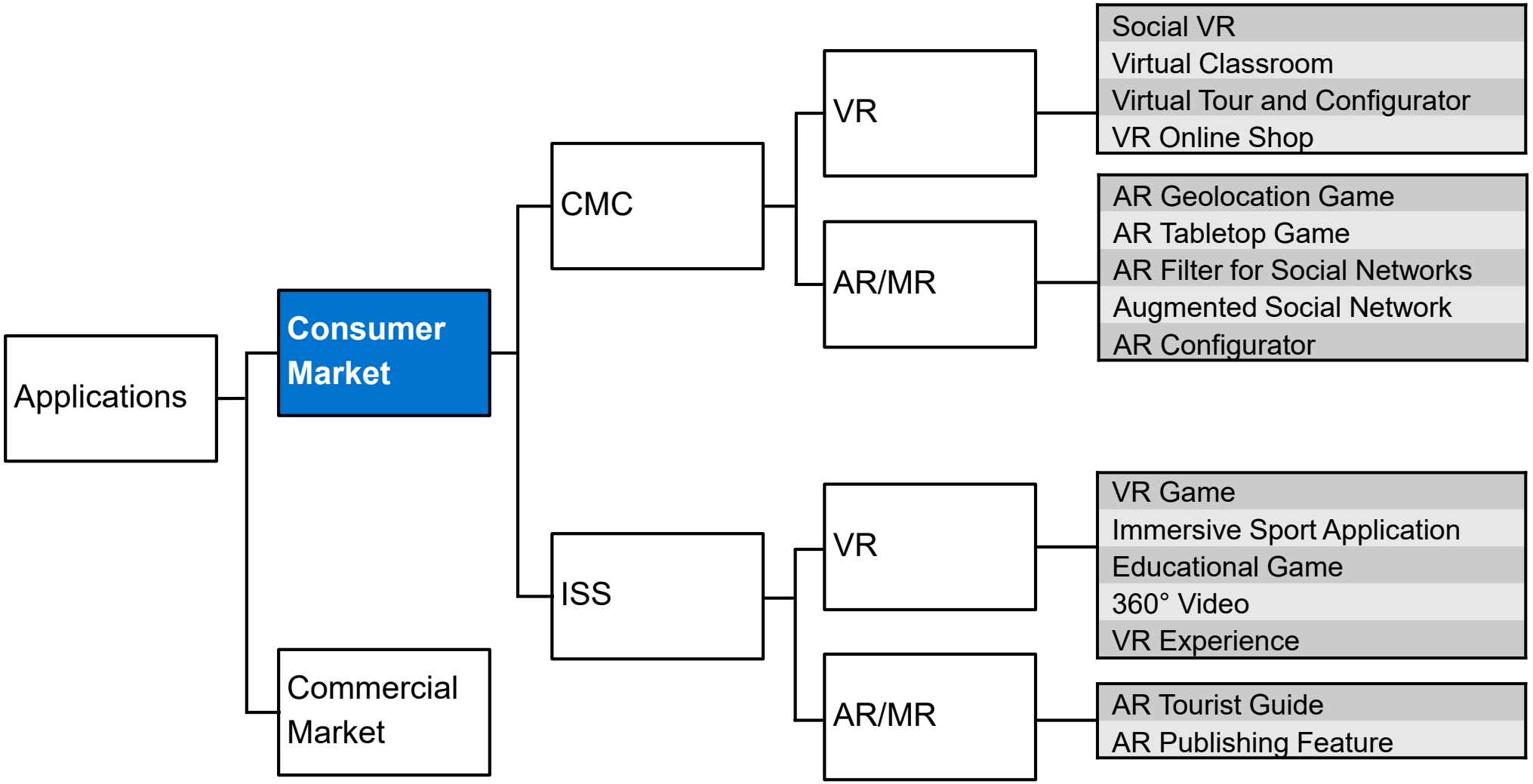
There are 16 consumer applications with a total of 9 VR applications and 7 AR/MR applications

Taxonomy of VR/AR/MR Applications (1/2)



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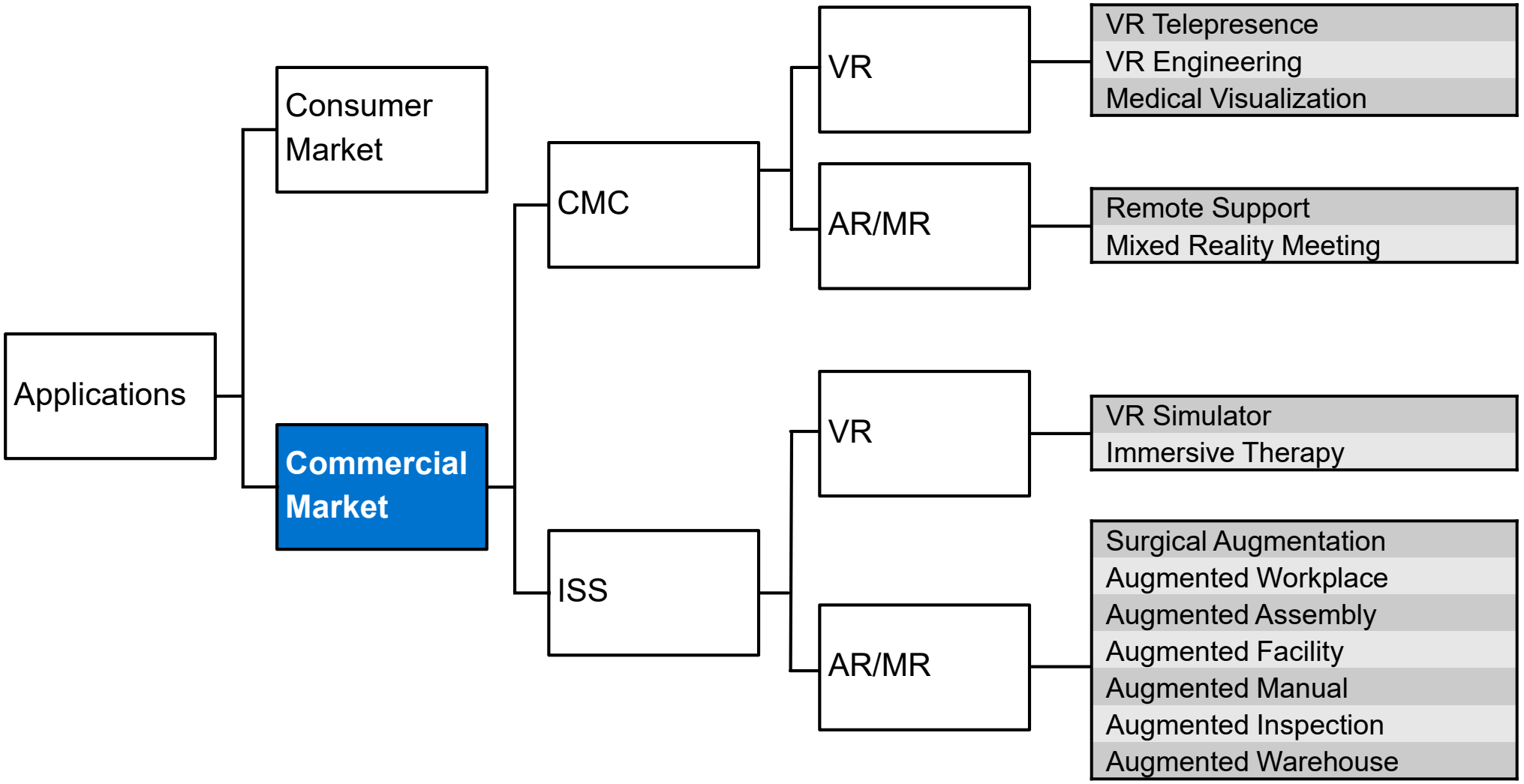
There are 14 commercial applications with a total of 5 VR applications and 9 AR/MR applications

Taxonomy of VR/AR/MR Applications (2/2)



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Diffusion of Technology

Explanatory Notes (1/2)

[Slide 14] The section “Diffusion of Technology” introduces key concepts of innovation diffusion and shows how VR, AR & MR hardware is related to VR, AR & MR applications. There exists a myriad of literature on the topic of innovation diffusion and innovation adoption. While innovation diffusion largely analyzes how innovations diffuse (e.g. speed) within a market or a social system, innovation adoption is mainly focused on innovation characteristics that induce individual entities (e.g. users, teams) to acquire and use the innovation. Therefore, the innovation characteristics relevant for adoption can affect the overall diffusion of an innovation on the market. In total, we analyzed eight popular theories on innovation adoption all of which are focused on the individual (i.e. user) level. Innovation characteristics relevant for innovation diffusion can however occur on each level-of-analysis. Thus, we derived five innovation characteristics: Performance/Pay Off, Complexity/Cost, Compatibility/Fit, Cognitive Absorption, Facilitating Conditions. These five characteristics directly affect the diffusion of the innovation on the market. In a time-adoption diagram, the cumulative adoption results in an S-shaped curve.

[Slide 15] The diffusion of innovations is often dependent on complementary innovations. Alongside their application specific innovation characteristics, their diffusion largely depends on the technological readiness of the underlying VR, AR & MR hardware. The effect of technological readiness on application diffusion is mediated through the innovation characteristic of facilitating conditions: If the technological readiness of the hardware is low, diffusion of the application will be impeded. While application specific innovation characteristics largely remain constant until the next technological paradigm emerges, technological readiness is a temporary factor that will be improved over time. The technological readiness of the hardware can in turn be assessed by evaluating the hardware along the innovation characteristics introduced earlier.

[Slide 16] Past research into innovation diffusion has shown that the progression of application diffusion can variate across innovations. In general, there are three relevant aspects: (1) The saturation level defines percentage of adopters measured relative to the total number of potential adopters in a given market. (2) The speed of diffusion defines how fast the application diffuses over the years (3) The year of inflection defines in which year the diffusion of an innovation starts. Looking back at our influencing factors, application specific innovation characteristics mainly affect the saturation level of an application and its speed of diffusion; Technological readiness of the hardware mainly influences the year of inflection and if the technological readiness improves gradually, it will influence the speed of diffusion.

[Slide 18] In this section we analyze the current technological readiness of VR and AR & MR hardware. Regarding VR hardware, in the year 2016 a total of 11.2 million devices were sold worldwide. The majority of sold devices (9.75 million) were Mobile VR HMDs. As mentioned in the introduction, current Mobile VR HMDs essentially consist of a don-able container with optical lenses into which a conventional smartphone is inserted. The high sales figures of Mobile VR can be attributed to the low acquisition costs of the containers ranging between USD 15-100 (Field, 2017a; Srivastav, 2017). Even though simple controllers are available for the devices, current Mobile VR devices offer a poor user experience. The lack of computational power, body and hand tracking limits the number of applications that can be used with the devices. For this reason, the IHS institute predicts a slightly decreasing number of Mobile VR HMDs in 2017. The situation looks markedly different for Tethered VR HMDs: Even though the devices themselves cost around USD 500 and the hosting computer hardware starts at USD 1000, the IHS predicts increasing sales figures (IHS 2017, Neiger, 2016; Vanian, 2017). We attribute this to the fact that on the consumer market the availability of user content is increasing and on the commercial market interest of

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Diffusion of Technology

Explanatory Notes (2/2)

companies surges. Even though there is a positive trend for viable (high-end) VR HMDs we see that the current device characteristics inhibit widespread diffusion. Next generation VR HMDs should primarily improve in the following domains: improved resolution, reduced overall cost (through reduced reliance on external hosting hardware), un-tethered/mobile devices, improved form factor (e.g. weight), inside-out tracking, recording facial expressions. When these characteristics improve, widespread diffusion of VR applications is possible. There are multiple indications that the next generation of VR devices will be released before 2020: (1) Oculus announced to release a mobile self-contained VR HMD in early 2018 (Matney, 2017; Stevenson, 2017). (2) Microsoft offers inside out motion tracking (Kipman 2017). (3) HTC Vive launches self-contained VR HMD in January 2018 (Lang 2018). (4) Companies such as Facebook and Veeso work on capturing facial expressions in VR (Irving, 2016; Simonite 2015).

[Slide 19] Handheld AR is currently the dominant hardware platform for delivering AR & MR applications. Through the release of ARkit (iOS) and ARcore (Android) on smartphones in 2017, there is effectively full availability of AR hardware on the consumer and corporate market (Bastian et al., 2017). Nonetheless, handheld AR is only a transitional solution: AR & MR HMDs promise compelling benefits when information is visible in the complete field-of-view rather than being limited to a 5-inch smartphone display. Even though AR HMDs have been in stock for many years, their sales figures remain low. In 2016, only 0.16 million AR HMDs were sold (IDC 2017). This bleak situation can be mainly attributed to the fact that superimposing 2D content at a fixed distance offers poor ergonomics. Users are constantly required to shift focus when switching between superimposed AR content and the real environment. This can lead to nausea and rapid fatigue. This situation is different for MR HMDs, where digital content can be merged naturally with the real environment. We predict that MR HMDs will emerge as the dominant hardware platform in the long run. However, MR devices are still a quite recent development. There are many innovation characteristics that need to be improved: improved tracking, improved battery life, improved computational power, reduced device cost, improved form factor, reduced weight and increased field-of-view. Unlike VR HMDs, next generation AR & MR hardware are still afar. Tim Cook (CEO, Apple) states that significant technological development is still required (Griffin, 2017). Consumer-ready MR HMDs might enter the market before 2030. Until then, Handheld AR will remain the major platform for delivering AR & MR applications. For specific commercial applications the sale of AR HMDs will continue to increase.

[Slide 21] Increased performance of the hardware drives application diffusion. This is especially true when a new generation of hardware with improved innovation characteristics emerges. Considering that viable VR HMDs will enter the market before 2020 and viable MR HMDs will enter the market before 2030, we predict that VR and AR & MR applications will diffuse in two phases. In phase 1 from 2020 to 2030, VR applications will see high diffusion rates. Moreover, there will be a strong diffusion of AR & MR applications that can be effectively used via Handheld AR devices (e.g. AR Configurator). In phase 2 from 2030 to 2040, AR & MR applications will see high diffusion rates. Moreover, there will be a diffusion of VR applications that require complex complementary innovations (e.g. rendering apparel on realistic avatars in VR online stores).

[Slide 22,23] Based on our in-depth analysis of applications, we predict in which phase applications will diffuse. Moreover, based on the application specific innovation characteristics, we predict the diffusion likelihood of each application ranging from high to low.

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There are five innovation characteristics that influence the diffusion of innovations

Innovation Characteristics influencing Innovation Diffusion

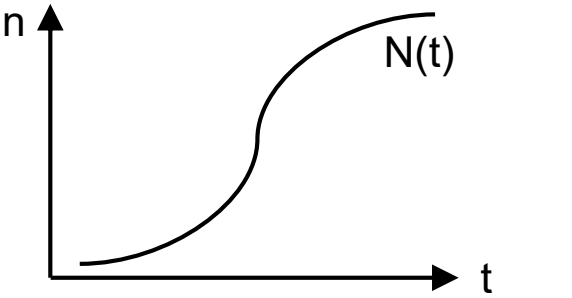
Influencing Factors

Innovation Character-istics

- **Performance / Pay-Off** — relative advantage · positive outcomes · usefulness · etc.
- **Complexity / Cost** — adoption cost · implementation effort · complexity of use · etc.
- **Compatibility / Fit** — social norms · existing environment · established processes · etc.
- **Cognitive Absorption** — positive psychological state · usability · immersiveness · motivation · etc.
- **Facilitating Conditions** — complementary technologies · network externalities · etc.

Innovation Diffusion

The cumulative innovation diffusion follows an S-shaped curve



n … percentage of adopters in a market
t … time
N(t) … cumulative adoption at time point t

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Additional to application characteristics the technological readiness of the hardware influences application diffusion

Application and Hardware as Complementary Innovations

Influencing Factors

Innovation Characteristics of Application

- Performance / Pay-Off
- Complexity / Cost
- Compatibility / Fit
- Cognitive Absorption
- Facilitating Conditions

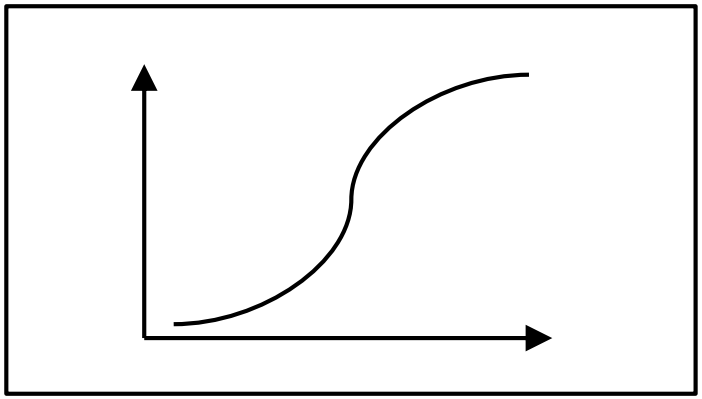
Application Level

Hardware Level

Innovation Characteristics of Hardware → **Technological Readiness of Hardware**

Application Diffusion

Applications and hardware are complementary innovations



Diffusion of a VR/AR/MR application depends on:

- Application specific innovation characteristics
- Technological readiness of the hardware

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Depending on application characteristics and technological readiness, adoption curves differ in their progression

Progression of Innovation Diffusion

Influencing Factors	Progression of Application Diffusion	
Application Specific Innovation Characteristics	Saturation level	**Defines the percentage of adopters in a market that will eventually adopt the application** · Largely defined by application specific characteristics
Application Level / Hardware Level	Speed of diffusion	**Defines how fast the application will diffuse** · Influenced by application specific characteristics and technological readiness of the hardware
Technological Readiness of Hardware	Year of inception	**Defines when the diffusion of an innovation starts** · Largely defined by the technological readiness of the hardware

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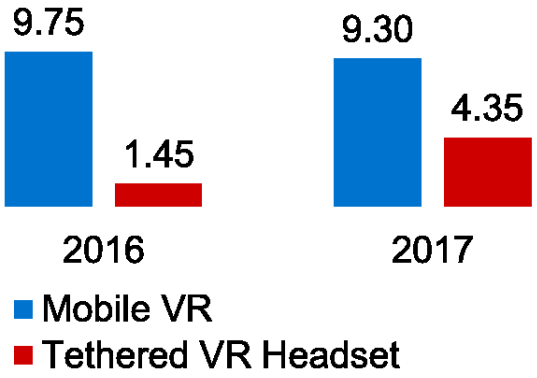
Current VR device characteristics inhibit widespread adoption but next generation devices might enter the market before 2020

Technological Readiness of VR Headsets

Current Hardware Solutions

Worldwide VR headset unit sales (in mil.) by device type 2016 and prediction for 2017



- Mobile VR acquisition costs are low, but only a small subset of VR applications can be used
- Tethered VR Headsets provide high graphical capabilities, but hardware is expensive and non-mobile

Hardware Evolution

Current VR hardware devices → Next Generation VR hardware devices

Perf. / Pay-Off	+ resolution
Compl. / Cost	+ reduced overall cost
Compa. / Fit	+ mobility + form-factor + inside-out tracking
Cognit. Absor.	+ recording facial expressions
Facilit. Cond.	+ availability of content + increased user base + input devices + common standards

Timeline

There are multiple indications, that the next generation of VR devices will be released before 2020:

- Oculus announced to release a mobile self-contained VR headset in early 2018 (Matney, 2017; Stevenson, 2017)
- Microsoft offers inside out motion tracking (Kipman 2017)
- HTC Vive launches self-contained VR headset in January 2018 (Lang 2018)
- Companies such as Facebook and Veeso work on capturing facial expressions in VR (Irving, 2016; Simonite 2015)

Source. Data: IHS (2017)

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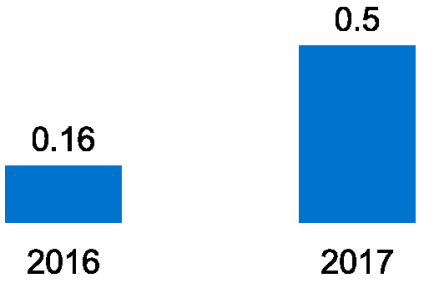
Consumer-ready MR headsets might enter the market before 2030 and emerge as the dominant technology for AR/MR applications

Technological Readiness of AR/MR Headsets

Current Hardware Solutions

Worldwide AR headset unit sales (in mil.) by device type 2016 and prediction for 2017



- AR headsets are available at reasonable prices, however superimposing 2D content at a fixed distance offers poor ergonomics
- MR headsets are a recent innovation offering good ergonomics, but field-of-view and form factor need improvement

Source. Data: IDC (2017)

Hardware Evolution

Current AR/MR hardware devices → Next Generation AR/MR hardware devices

Perf. / Pay-Off	+ tracking + battery life + computational power
Compl. / Cost	+ reduced device cost
Compa. / Fit	+ form factor + reduced weight
Cognit. Absor.	+ field-of-view + MR rather than AR
Facilit. Cond.	+ availability of input devices

Timeline

As AR headsets offer poor ergonomics and limited possibilities compared to MR headsets, AR headsets are likely to be substituted by MR headsets

MR headsets are still in an early stage · Industry experts argue that consumer-ready MR headsets could enter the market before 2030, e.g.:

- Tim Cook (CEO, Apple) states that significant technological development is still required (Griffin, 2017)

Handheld AR will remain the major platform for delivering AR/MR applications until the introduction of consumer-ready MR headsets

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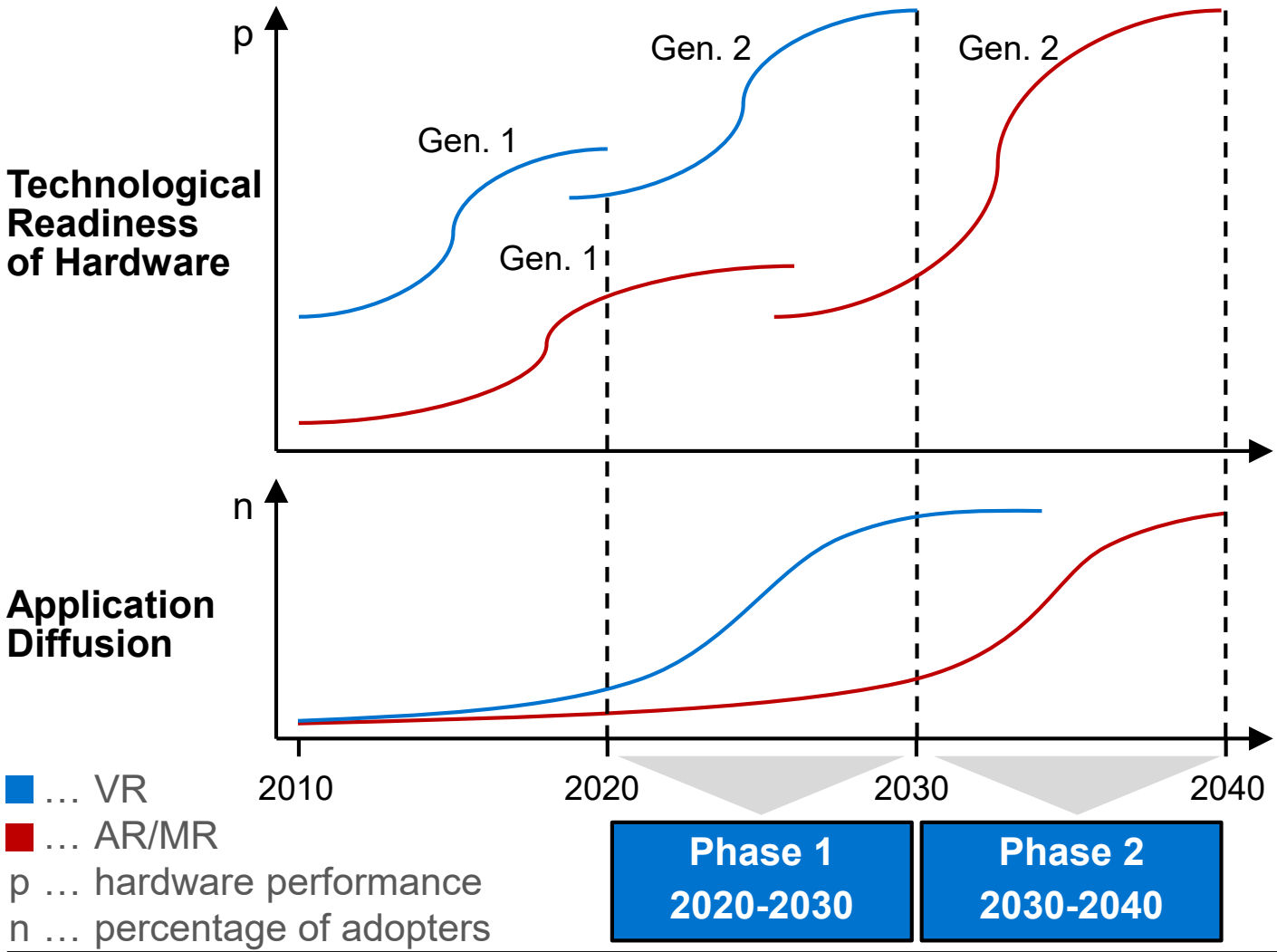
Depending on hardware performance, VR and AR/MR applications will diffuse in two phases from 2020-2030 and 2030-2040

Temporal Diffusion of VR and AR/MR Applications



VR/AR/MR applications will diffuse in two phases between 2020 and 2040

- Improved VR hardware (Gen. 2) might enter the market before 2020
- Improved AR/MR hardware (Gen. 2) might enter the market before 2030

VR applications might see high diffusion rates in Phase 1 2020-2030 · Except VR applications requiring complex complementary innovations which will diffuse in Phase 2

AR/MR applications might see high diffusion rates in Phase 2 2030-2040 · Except AR/MR applications used on handheld AR which will diffuse already in Phase 1

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In Phase 1, VR games, VR online shops, virtual classrooms, and AR configurators will see highest diffusion

Saturation Level of Consumer VR/AR/MR Applications

Saturation Level	Diffusion Phase 1 (2020-2030)	Diffusion Phase 2 (2030-2040)
High	• VR Game • Virtual Tour and Configurator • VR Online Shop • Virtual Classroom • AR Filter for Social Networks • AR Configurator	• Augmented Social Network • AR Tourist Guide
Medium	• Educational Game • VR Experience • Social VR	• AR Geolocation Game
Low	• 360° Video • Immersive Sport Application	• AR Tabletop Game • AR Publishing Feature

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In Phase 1, telepresence, engineering, simulators, and remote support will see highest diffusion

Saturation Level of Commercial VR/AR/MR Applications

Saturation Level	Diffusion Phase 1 (2020-2030)	Diffusion Phase 2 (2030-2040)
High	• VR Telepresence • VR Engineering • VR Simulator • Remote Support	• Augmented Manual • Surgical Augmentation
Medium	• Medical Visualization • Augmented Facility	• Mixed Reality Meeting • Augmented Workplace • Augmented Assembly
Low	• Immersive Therapy • Augmented Inspection	• Augmented Warehouse

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Impact on Industries

Explanatory Notes (1/3)

[Slide 28] The section “Impact on Industries” analyzes how the introduced VR and AR & MR applications affect particular industries. For this purpose, we measure the impact of 30 applications on 41 industries. If an innovation can be utilized within a particular industry, it can impact the industry in different ways: (1) When it has an incremental effect on the industry, the innovation does not represent a major departure from existing practices. Therefore, the innovation can be considered an incremental innovation. (2) When it has a radical effect on the industry, the innovation represents a major departure from existing practices. Therefore, the innovation can be considered a radical innovation. Radical innovations can trigger a process of industrial change: The current market situation changes through the introduction of the innovation to the market, which results in a state after the introduction. The change, which was induced through the radical innovation, can be measured as the impact on the industry.

[Slide 30,31] To assess the nascent industrial change, VR, AR & MR applications were matched to an exhaustive set of industries. For each application-industry-pair, we analyzed if the effect of the application introduction is radical or incremental. In total, we identified seven industries that are subject to radical change.

[Slide 33] Regarding the communication and IT service industry, we predict that Social VR will establish itself on the market as users can spend quality time with friends in VR. While people have the urge to stay connected and spend time with friends over a distance, current technology (e.g. Video Chat, Text Chat, Social Networks, Online Games) offer only limited means to fulfill this need. Social VR can cater to these user needs: Users can talk with friends virtually through seeing them face-to-face; Users can make new experiences with friends instead of being limited to sharing information through narration. Therefore, we predict that Social VR will establish itself on the market between 2020 and 2030.

[Slide 34] Regarding the communication and IT service industry, we predict that Social VR for dating will substitute large parts of conventional online dating experiences. While online dating has emerged as a popular means of getting to know romantic partners, search costs are still high: Profile pictures and Chat might be inadequate to judge how well users resonate with each other; Video calls might feel odd to many users. Social VR for dating might significantly reduce search costs, as users have a more immersive means of meeting one another face-to-face online. Therefore, we predict that Social VR for dating will substitute large parts of conventional online dating experiences between 2020 and 2030.

[Slide 35] Regarding the music industry, we predict that VR Experiences will disrupt the music industry. While the music industry became increasingly dependent on the sale of concert tickets, concert goers face significant limitations: Ticket prices are often high; Seats might be distant from the main stage; Repercussion effects might inhibit optimal audio; Concerts are at location and time dependent. VR Experiences could provide an improved experience to concert goers: Consumption is possible at any time in any location; Consumption is possible even if the performer has retired or passed away; Spectators can be on the stage with the performers in VR; Concerts can be delivered in high audio and video quality. Therefore, we predict that VR Experiences will disrupt the music industry between 2020 and 2030.

[Slide 36] Regarding the education industry, we predict that distance education institutions will win over market shares from bricks-and-mortar education institutions through new ways of delivering education to students. While distance education institutions can offer substantial benefits to students compared to bricks-and-mortar institutions, students in Germany and the US prefer receiving their education from bricks-and-mortar institutions: Distance education can

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Impact on Industries

Explanatory Notes (2/3)

lead to an isolated learning experience, requiring a high degree of student-initiative. Virtual Classrooms could improve students' motivation and learning effects: Virtual Lectures and Visualizations can make the delivery of educational contents more immersive; Face-to-face communication with lecturers and tutors can increase student motivation and learning; Conduction teamwork with fellow students in VR could make the learning experience more interactive. Therefore, we predict that distance education institutions win over market shares from bricks-and-mortar education institutions between 2020 and 2030.

[Slide 37] Regarding the retail industry, we predict that the spatial visualization of furniture items will lead to growth of online furniture sales. While the share of online furniture sales from total furniture sales has been lagging behind other online product categories, the possibilities introduced through AR configurators seem to hold great potential: Customers can better imagine furniture items in their home; Customers do not need to take measurements; Customers can easily decide between different configurations; Customers can discuss interior solutions with friends and family. Therefore, we predict that online furniture sales will increase between 2020 and 2030.

[Slide 38] Regarding the retail industry, we predict that viewing products in VR and receiving virtual customer support will establish VR Online Shops as an additional online sales channel. While eCommerce became an important sales channel for the retail industry, bricks-and-mortar stores still have the advantage of being able to present the physical product in life-size and providing customer advice. VR can close the gap between the online and offline retail trade: Customers can view the product virtually in life-size; Customers can receive virtual customer advice. Therefore, we predict that VR Online Shops will emerge as an additional sales channel between 2020 and 2030.

[Slide 39] For fashion retailers, the implications of VR Online Shops could be even more fundamental: Rendering clothes on avatars could overhaul the complete online apparel sales process. VR Online Shops for apparel might emerge between 2030 and 2040.

[Slide 40] Regarding the real estate industry, we predict that VR-enabled sales processes will become industry standard for new building projects. To sell building projects to (commercial or private) clients, real estate developers and agents rely heavily on construction visualizations and physical prototypes. Virtual Tours and Configurators can however enhance the sales process: Prototyping costs can be reduced; Visualizations can be improved; Management of customer requirements for the interior design can be improved; Conversion rate can be increased. Therefore, we predict that VR-enabled sales processes will become industry standard for new building projects between 2020 and 2030.

[Slide 41] Regarding the manufacturing industry, we predict that supporting design and planning through VR will reduce costs, increase productivity and yield further positive outcomes. Conventional design and planning processes can be unproductive and lead to process inefficiencies and expensive mistakes. VR Telepresence, VR Engineering and VR for Digital Twins can help improving design and planning processes: Collaboration can be made more effective; Functional silos can be reduced; Travel costs can be reduced. Therefore, we predict that VR-enabled design and planning processes will reduce costs and increase productivity of manufacturers between 2020 and 2030.

[Slide 42] Regarding the manufacturing industry, we predict that augmented facilities and augmented manuals will increase the productivity of shop floor workers. While maintenance and repair processes are key to successfully operate plants, process complexity, documentation needs and IoT-machinery cause shop floor workers to

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Impact on Industries

Explanatory Notes (3/3)

lag behind the technological development. Augmented facilities and augmented manuals can increase worker's productivity: Maintenance technicians can be guided to the correct incident location; Workers can be provided with the right information at the right time in the right place; Workers can be guided through process steps; Information can be recorded automatically in the backend system; etc. Therefore, we predict that augmented facilities and augmented manuals will increase the productivity of shop floor workers between 2020 and 2030.

[Slide 43] Regarding the automotive aftermarket, we predict that through the digitalization of maintenance and repair related knowledge car workshops can increase their productivity. Car mechanics are confronted with an increasing complexity and diversity of technologies as well as an increasing level of job requirements. Augmented Manuals and VR Simulators for training can help car workshops to: adapt to new technologies; increase productivity; reduce liabilities through improved documentation; reduce training costs; offer just-in-time trainings; reduce dependence on individual experts. Therefore, we predict that car workshops can increase their productivity between 2030 and 2040.

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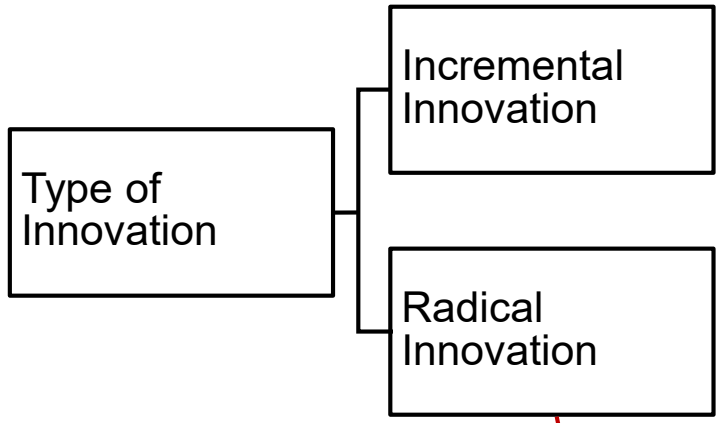
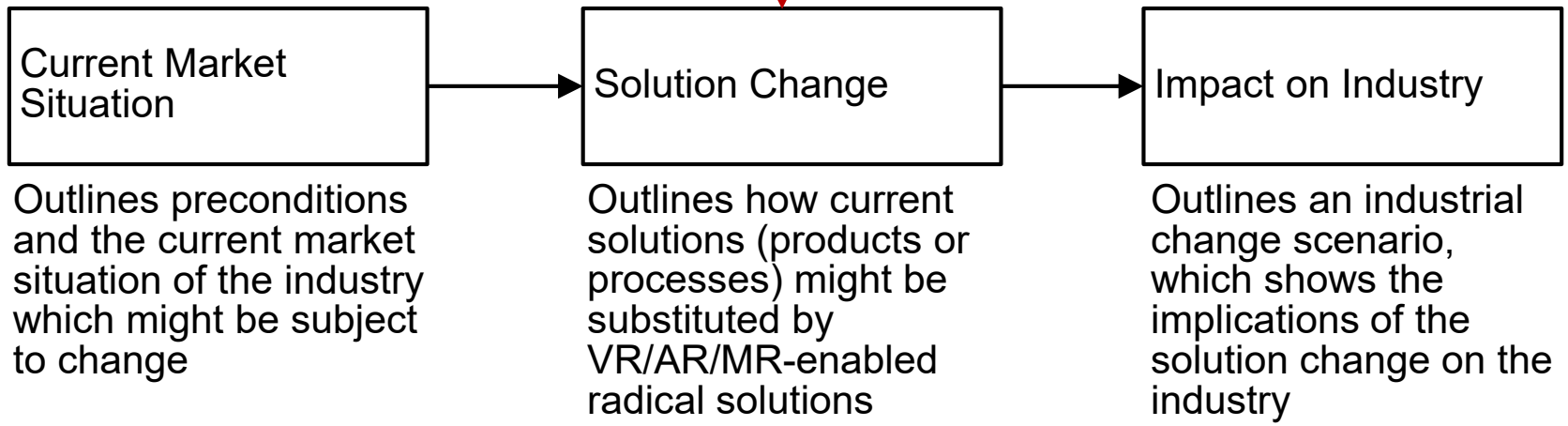
Depending on the particular industry, innovations can be radical and trigger a process of industrial change

Types of Innovation and their Impact on Industrial Change

How can the impact of an innovation be assessed?



How do industries change?



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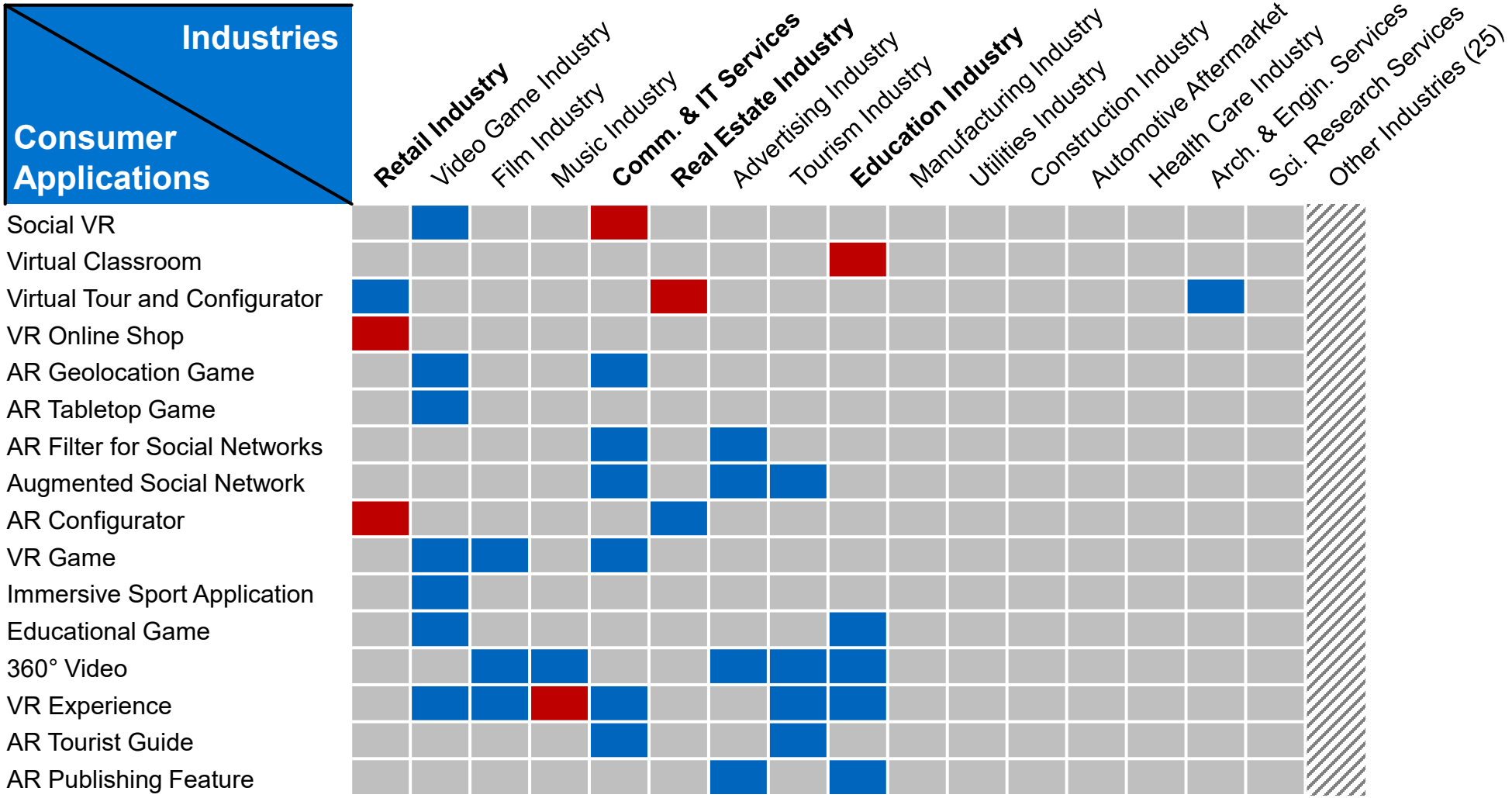
Impact of Virtual, Mixed, and Augmented Reality on Industries

Agenda

DOI: 10.14459/2018md1454069

Assessing the impact of 16 consumer applications uncovered a radical effect on 5 industries

Assessing the Impact of Consumer Applications on Industries



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no effect
incremental effect
radical effect

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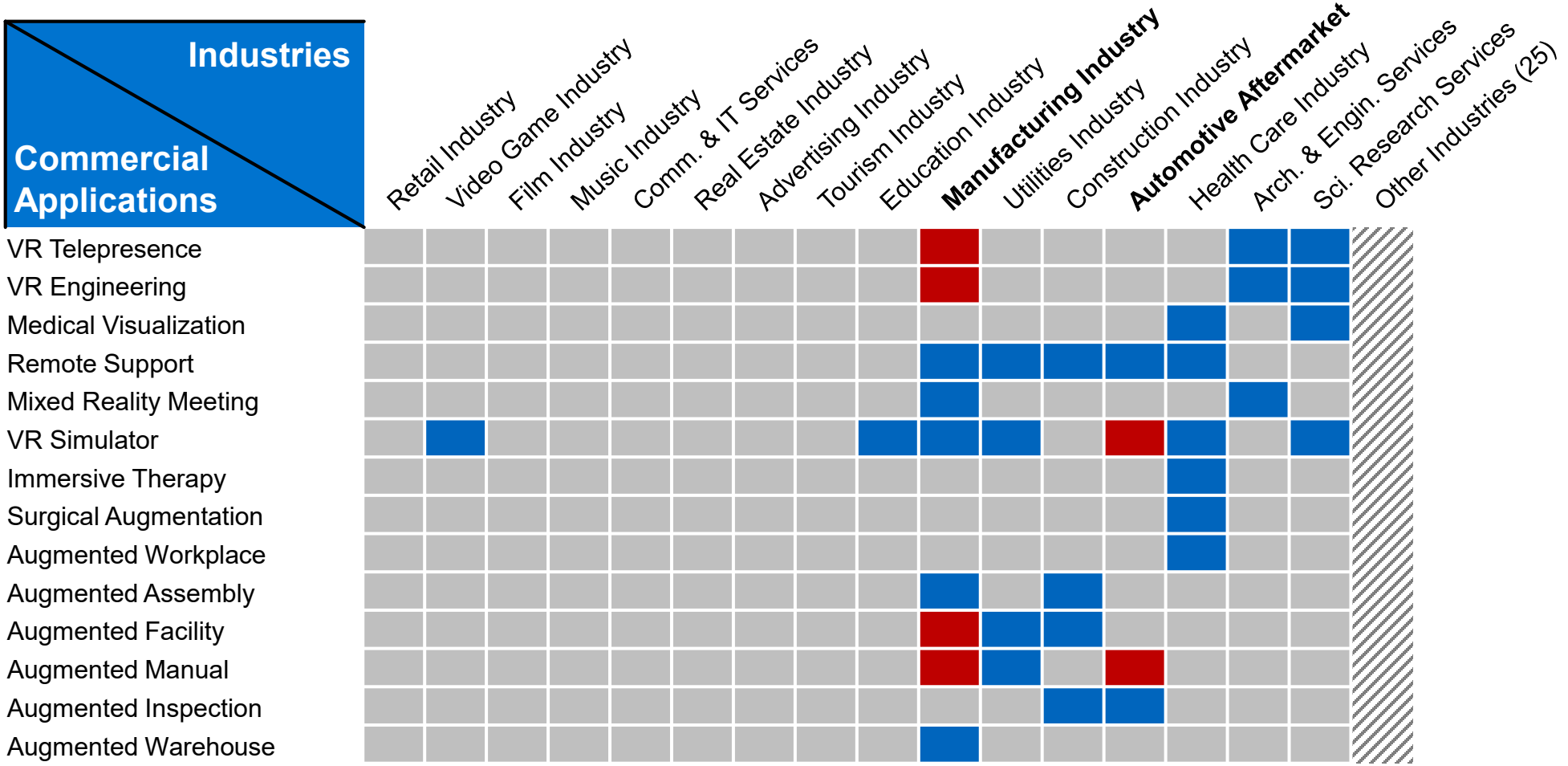
Assessing the impact of 14 commercial applications uncovered a radical effect on 2 industries

Assessing the Impact of Commercial Applications on Industries



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Impact of Virtual, Mixed, and Augmented Reality on Industries

Agenda

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Spending quality time with friends in VR will allow Social VR to establish itself on the market

Communication and IT Service Industry

SIM.TUM Strategic and International Management

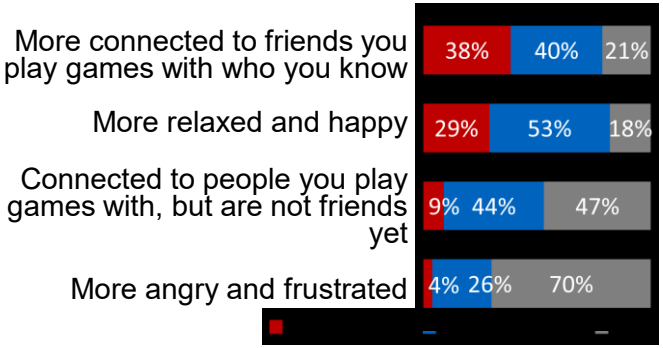
Change Period: 2020-2030

Current market situation

Social networks allow users to stay connected with friends

However, social networks might not be optimal to spend intensive quality time with friends online

Online games allow users to spend quality time with friends



Note. Self-reported emotional state of teens who play games with other people. The figure illustrates that online gaming allows people to spend (perceived) quality time with friends. Source. Pew Research (2015).

Solution change

How do people spend time with close friends via elect. media?

- Instant Messaging
- Social Network
- Online Game

→ Social VR

Perf. / Pay-Off	+ spend quality time with friends
Compl. / Cost	*(not affected)*
Compa. / Fit	- cannot be used during transit
Cognit. Absor.	+ make new experiences + face-to-face communication
Facilit. Cond.	+ possible intersection with VR Games

Impact on industry

- Social VR will emerge as a prime medium to spend time with close friends over a distance
- However, Social VR is not a substitute for conventional Social Networks

Implications for Stakeholders

- Offering a broad range of VR Games and Experiences will be a key success factor for Social VR Communities
- Game Publishers could use the opportunity to create VR communities based on their existing gaming communities

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VR based online dating will emerge as an alternative to conventional online dating experiences

Communication and IT Service Industry

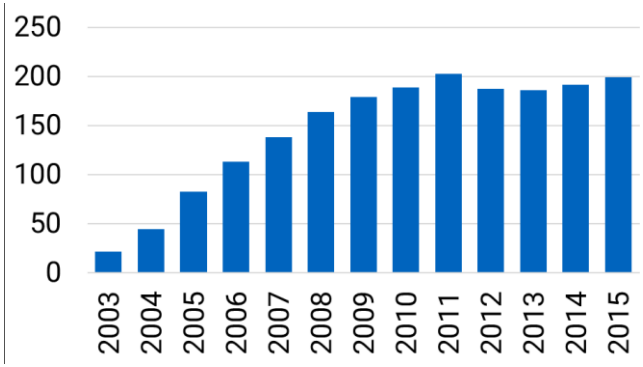
SIM.TUM Strategic and International Management

Change Period: 2020-2030

Current market situation

Through the internet, people can meet romantic partners online

Online Dating evolved into a substantial market in Germany and worldwide



Note. Revenues of German Online Dating Communities between 2003 and 2015 (in million EUR). The figure illustrates that online dating has established a substantial market. Source. Singelbörsen-Vergleich (2016).

Solution change

How do people meet potential romantic partners online?

- Online Dating Community
- Social VR (for dating)

Perf. / Pay-Off	+ reduce false-positives through virtual face-to-face communication
Compl. / Cost	+ reduced search costs of participants
Compa. / Fit	+ insecurity over initial contact can be attenuated in VR
Cognit. Absor.	+ immersive conversations improve user experience
Facilit. Cond.	+ willingness to pay for dating services on the internet

Impact on industry

- VR-based online dating will emerge as a new type of online dating platform
- VR-based online dating will partially substitute conventional online dating communities

Implications for Stakeholders

- Incumbent online dating communities should evaluate the opportunity and create own VR dating features
- New entrants have a high opportunity of establishing on the online dating market

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Digitalization of concert performances can potentially disrupt the music industry

Music Industry

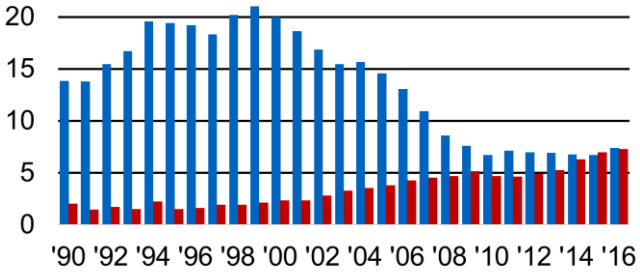
Strategic and International Management

Change Period: 2030-2040

Current market situation

In 2000, revenues from record sales started to dwindle.

Live concert ticket sales became an important revenue source for the music industry



Note. Total inflation-adjusted revenues from record music sales in the US (blue) and concert ticket sales in North America (red) between 1990 and 2016 (in billion USD). The figure illustrates the music industry's increasing dependence on concert ticket sales. Source. Bureau Of Labour Statistics (2017), Pollstar (2017), RIAA (2017).

Solution change

How can people experience a performance of a music group?

- Live Concert
- 360° Video
- VR Experience

Perf. / Pay-Off	+ reproducibility could increase total revenues
Compl. / Cost	+ overall cost lower for consumer
Compa. / Fit	+ time and location independent reproducibility + persistent "time capsule"
Cognit. Absor.	+ distance to performer + optimal audio and video - lack of social aspects
Facilit. Cond.	+ piracy of 360° Video and Experiences is difficult

Impact on industry

- An increasing number of concert performances will be digitalized and consumed in VR
- VR concert experiences will partially substitute the sale of concert tickets

Implications for Stakeholders

- Publishers and record labels should think of new business models to capture the value from the innovation which can be disruptive
- Technology providers should create solutions for the recording and reproduction of VR concert experiences

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Through improved educational offerings, distance education institutions will strengthen their position

Education Industry

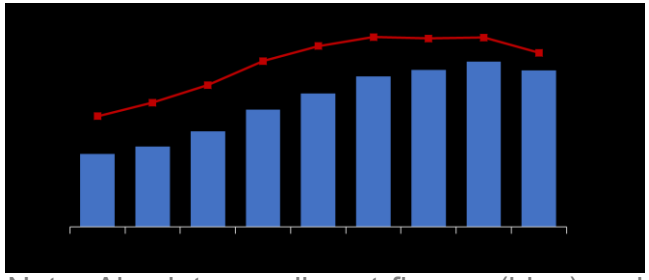
SIM.TUM Strategic and International Management

Change Period: 2020-2030

Current market situation

The internet transformed the way in which distance education can be delivered to students

However, the share of distance education enrollments remains low in Germany (and the US)



Note. Absolute enrollment figures (blue) and relative number of students compared to total enrollments at institutions of higher education (red) of students enrolled at distance education institutions in Germany 2006-2014 (in thousands). The figure illustrates the stagnating market for distance education. Source. Fretter and Grün (2015), Statistisches Bundesamt (2017).

Solution change

How do distance education institutions deliver contents to students?

• Conventional Online-Course → • Virtual Classroom

Perf. / Pay-Off	+ new educational methods improve educational quality
	+ learning and retention
Compl. / Cost	- teachers might lack skills for creating 3D content
Compa. / Fit	+ improved face-to-face communication with teachers and students
Cognit. Absor.	+ increased motivation through immersive content and tighter social bonds
Facilit. Cond.	+ differentiator for institutions

Impact on industry

- Delivering education via VR will increase the share of students enrolled at higher education distance education institutions
- The traditionally low share of bachelor students at distance education institutions will be increased

Implications for Stakeholders

- Technology providers should create platforms in which educational contents can be delivered via VR
- Distance education institutions should monitor for viable V-based education systems
- VR-based education will be a key differentiator for institutions

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Spatial visualization of furniture items will lead to growth of online furniture sales

Retail Industry

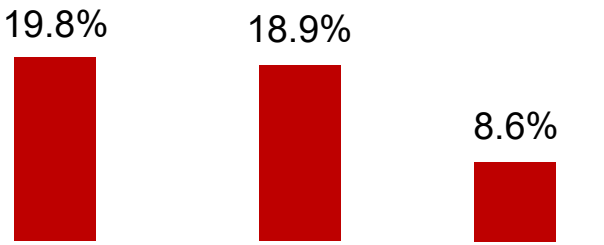
SIM.TUM Strategic and International Management

Change Period: 2020-2030

Current market situation

Through the internet, online commerce has emerged as an important sales channel

However, the online sale of furniture is lagging behind other product categories



Note. Revenue share of e-commerce of total commerce in Germany in 2013 by product category. The figure illustrates that online furniture sale is lagging behind other product categories. Source. IfH Köln (2014).

Solution change

How do people buy furniture that fits their homes?

- Bricks-and-Mortar Store
- Online Shop

→ AR Configurator

Perf. / Pay-Off	+ expedited decision process
Compl. / Cost	+ reduces the need of customers to take manual measurements
Compa. / Fit	+ customers can be provided with design proposals + share configuration images
Cognit. Absor.	+ it becomes easier for customers to imagine furniture in their home
Facilit. Cond.	+ effective use on handheld devices

Impact on industry

- AR Configurators will emerge as an important sales channel for online furniture sales
- The online revenue share of total furniture sales will increase
- Increased price pressure might lead to consolidation on the bricks-and-mortar market

Implications for Stakeholders

- Online furniture retailers should prepare their inventory management system (3D data, digital texture samples, etc.)
- Manufacturers should make 3D data of furniture items readily available

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VR online shops will establish as an additional online sales channel

Retail Industry

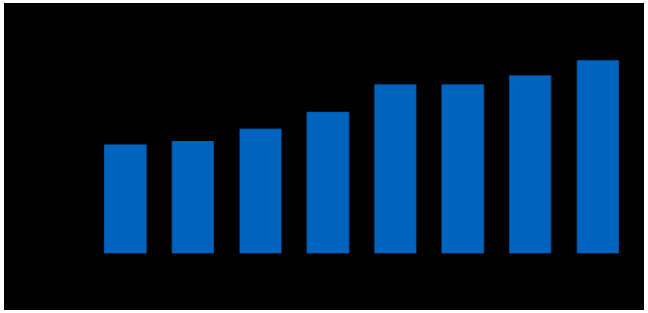
SIM.TUM Strategic and International Management

Change Period: 2020-2030

Current market situation

Through the internet, online commerce has emerged as an important sales channel

However, sales in bricks-and-mortar stores remain high as they provide customer advice, physical product-previews and the option of instant purchase



Note. Share of e-commerce in total retail revenue in Germany from 2009 to 2016. Although online shopping offers multiple advantages, sales in bricks-and-mortar stores remain high. Source. Bundesverband E-Commerce und Versandhandel e.V. (2017)

Solution change

How do consumers buy products online?

• Conventional Online Shop → • VR Online Shop

Perf. / Pay-Off	+ customer service increases conversion rates
Compl. / Cost	+ improved product selection will reduce return rates
Compa. / Fit	+ new ways of providing customer service
Cognit. Absor.	+ customers have an improved imagination of products
Facilit. Cond.	+ VR could be an extension of conventional online stores

Impact on industry

- VR Online Shops will emerge as an additional online sales channel
- (Human) customer service will be delivered in VR
- Delivering customer service in VR might lead to the growth of the call center market

Implications for Stakeholders

- Technology providers should create VR shop technology
- Online retailers should observe the market for viable VR Shop technology

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Fitting clothes to avatars will change the process of selling fashion and apparel online

Retail Industry

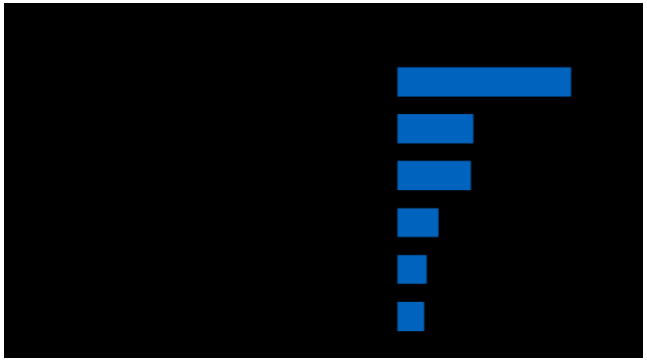
SIM.TUM Strategic and International Management

Change Period: 2030-2040

Current market situation

Online fashion and apparel shopping is popular with consumers

However, the online apparel product category faces high return rates



Note. Percentage of online customers who returned purchased items by category in the US in 2016. The figure illustrates that customers are more likely to return clothing items than items from other product categories. Source. Optoro (2017).

Solution change

How do consumers buy clothes online?

- Fashion Online Shop
- VR Online Shop
- Virtual Tour and Configurator
- AR Configurator

Perf. / Pay-Off + increased conversion rates

Compl. / Cost + fitting clothes to virtual avatars will reduce return rates

Compa. / Fit + customer service can enhance the experience

Cognit. Absor. + high engagement when fitting clothes to avatars

Facilit. Cond. + VR glasses are not the only medium to display configur-ations they can be viewed on smartphones as well

Impact on industry

- Avatar-based fashion and apparel sales will emerge as a prime sales channel for buying apparel online

Implications for Stakeholders

- For online fashion retailers, capabilities for fitting fashion to avatars will be strategically differentiating
- Many opportunities for technology providers (3D model creation of apparel, rendering of apparel, creation of avatars, etc.)

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Virtual Tours and Configurators will become industry standard in the marketing of new building projects

Real Estate Industry

Strategic and International Management

Change Period: 2020-2030

Current market situation

Apart of computer visualizations, the marketing of new building projects has remained largely traditional

However, the real estate marketing process is changing rapidly:

- customers expect optimal visualizations of building projects
- customers expect fast incorporation of design changes
- physically prototyping building interiors becomes too costly, inflexible and time-intensive
- equipment requests for the interior need to be managed efficiently

Solution change

How do real estate developers and agents market and equip new building projects?

- Construction Visualization
- Physical Prototype

→

- Virtual Tour and Configurator

Perf. / Pay-Off	+ increased conversion rates
Compl. / Cost	+ potential cost reduction in customer management, prototyping, customization + expedited sales process
Compa. / Fit	+ customers expect more information and choices
Cognit. Absor.	+ improved communication with customers
Facilit. Cond.	+ reusability of virtual objects

Impact on industry

VR Demonstrators will become the new industry standard for the marketing and interior fitting of new building projects

Implications for Stakeholders

- Real estate agencies and builders should adopt the technology
- Technology providers should consider if value chain could be disintermediated through including various furniture retailers in their system

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VR Telepresence and VR Engineering solutions will see broad adoption in the manufacturing industry

Manufacturing Industry

SIM.TUM Strategic and International Management

Change Period: 2020-2030

Current market situation

Product design and production planning are key functions of manufacturers and define the overall productivity and profitability of the company

However, processes for product design and production planning can be inefficient:

- low-functional integration leads to multiple feedback loops
- costly errors at an early stage
- high travel related costs
- ineffective communication with stakeholders

Solution change

How do teams and departments align on design and planning of products and processes?

- 2D Presentation
- CAVE Technology

→

- VR Telepresence
- VR Engineering

Perf. / Pay-Off	+ substantial productivity benefits + process reengineering
Compl. / Cost	+ reduced costs (e.g. travel costs)
Compa. / Fit	+ functional integration processes and departments
Cognit. Absor.	+ improved collaboration in teams
Facilit. Cond.	+ in line with digitalization and IT-integration endeavors

Impact on industry

- Supporting design and planning through VR will reduce costs and increase productivity
- VR-based planning and design solutions will see high adoption in the manufacturing industry

Implications for Stakeholders

- Manufacturers should identify processes that could benefit from VR support
- There are many technology providers on the market with whom manufacturers should get in touch

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Augmented Facilities and Augmented Manuals increase the productivity of shop floor workers

Manufacturing Industry

SIM.TUM Strategic and International Management

Change Period: 2020-2030

Current market situation

Maintenance, repair and operation tasks are a key function for the successful operation of production facilities

Costs related to maintenance, repair and operation tasks are increasing:

- increasing complexity of machinery
- increasing documentation overhead
- employees need to access data from backend systems

Solution change

How do production facilities sustain operations, handle incidents and reduce down-time?

- Conventional Maintenance, Inspection and Repair Process
- Augmented Facility
- Augmented Manual

Perf. / Pay-Off	+ increased productivity of employees
Compl. / Cost	+ cost saving potential + avoid expensive mistakes
Compa. / Fit	+ fluent interaction between humans and the Internet of Things
Cognit. Absor.	+ facilitated/interactive work allows flow experience
Facilit. Cond.	+ in line with digitalization and IT-integration endeavors

Impact on industry

- AR-solutions will increase the productivity of shop floor workers
- AR-solutions will see high adoption in the manufacturing industry

Implications for Stakeholders

- Manufacturers should identify processes that could benefit from AR support
- Manufacturers should get in touch with technology providers
- Technology providers should facilitate the process of content creation

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Through digitalized knowledge, car workshops can increase their productivity

Automotive Aftermarket

SIM.TUM Strategic and International Management

Change Period: 2030-2040

Current market situation

Cars are going through rapid technological development

In parallel, the work of car mechanics becomes increasingly complex and "half-time" of knowledge is decreasing:

- variety of drive technologies (combustion, electronic, hybrid, hydrogen-powered)
- technologies/ parts/ configurations can vary between different car models
- introduction of additional technologies such as Adaptive Driver Assistant Systems (ADAS)

Solution change

How can car mechanics access the knowledge required for their work?

- Paper Manual
- Training

→

- Augmented Manual
- VR Simulator

Perf. / Pay-Off	+ increased productivity of employees
Compl. / Cost	+ red. training requirements + red. dependence on experts
Compa. / Fit	+ "digital natives" expect support through technology
Cognit. Absor.	+ facilitated/interactive work allows flow experience
Facilit. Cond.	+ digitalized knowledge can be scaled

Impact on industry

- AR Manuals will see high adoption in the automotive aftermarket
- VR Simulators will become a standard for educating car mechanics

Implications for Stakeholders

- Car Workshop should evaluate and adopt the technology when it enters the market
- Car Manufacturers should collaborate with solution providers to facilitate the creation of augmented manuals for their vehicles

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Impact of Virtual, Mixed, and Augmented Reality on Industries

Appendix

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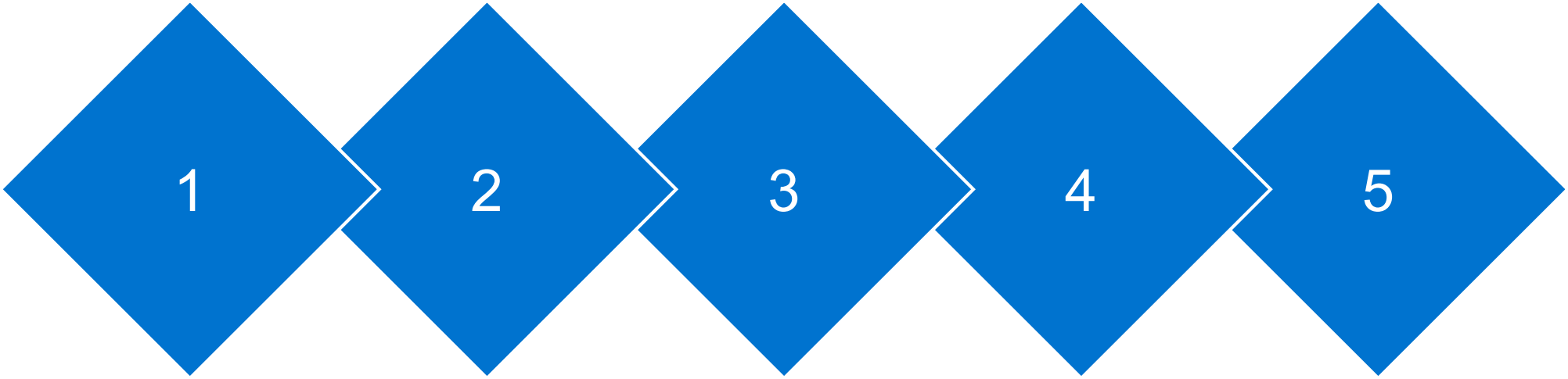
Different research approaches were combined to asses the impact of VR and AR/MR applications on industries

Methodology Overview



Deriving Industries
Deriving an appropriate set of industries from an industry classification standard

Measuring Venture Activity
Measuring the VR/AR/MR-related activities of start-ups in the derived industries

Application Identification
Identifying a set of VR and AR/MR applications that covers the innovations introduced through VR/AR/MR technology

Evaluating Hardware & Applications
Predicting application diffusion based on an evaluation of VR/AR/MR hardware and applications

Assessing the Impact on Industries
Matching applications to industries and uncovering how radically applications affect industries

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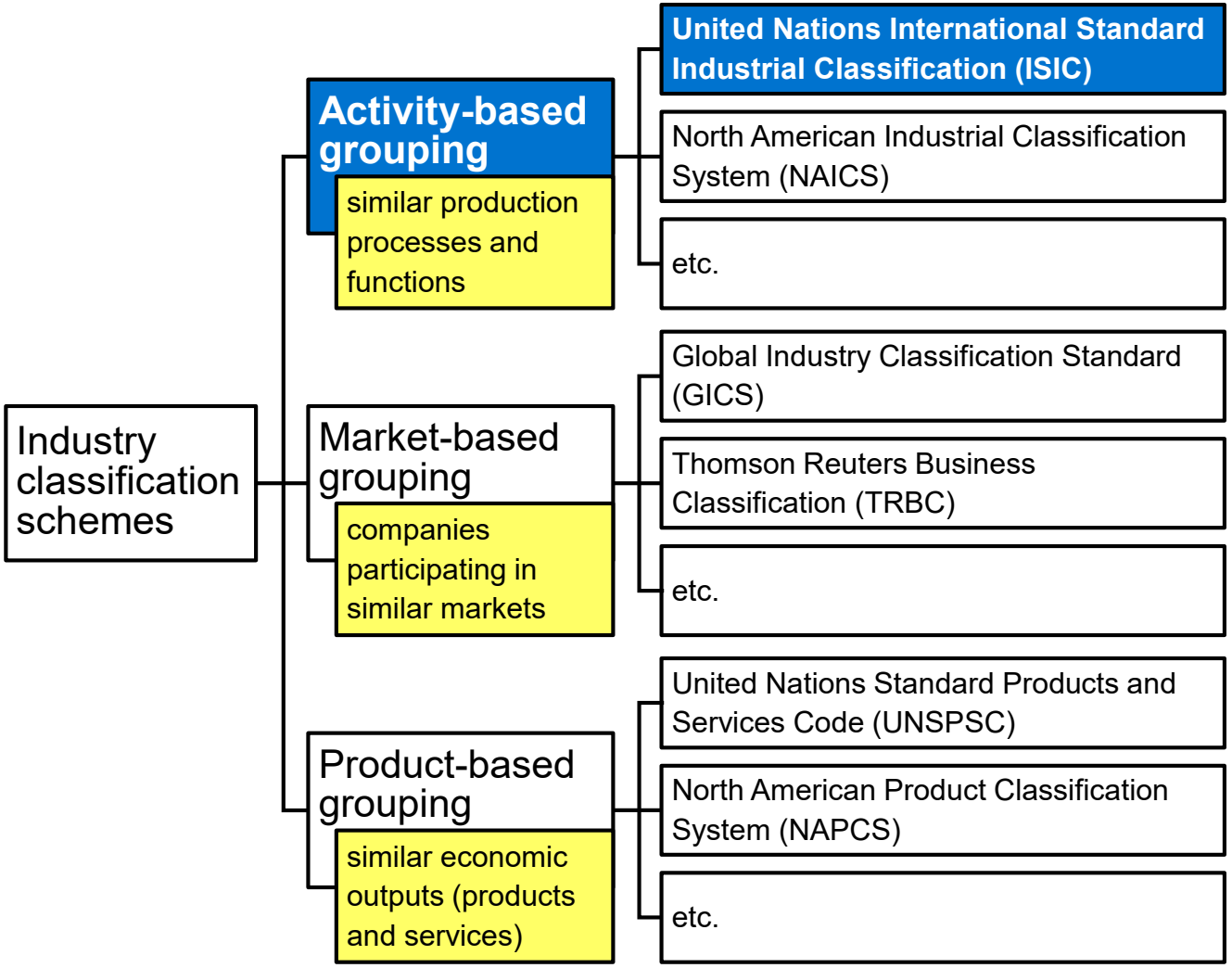
The activity-based ISIC standard is the adequate industry classification scheme for this research

[Deriving Industries] Selecting an Industry Classification Scheme



The activity-based ISIC standard is the adequate industry classification scheme for this research

Activity-based grouping is preferable as:

- similar production processes require the use of similar VR/AR/MR solutions
- the taxonomy is exhaustive · compared to market-based groupings it considers both the private and the public sector (e.g. education, military)
- it is used by governments

ISIC is preferable as:

- it is an activity-based taxonomy
- it is the most international scheme
- it is highly established

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To operationalize the analysis along industries the ISIC grouping needs to be restructured

[Deriving Industries] Outlining the United Nations International Standard Industrial Classification (ISIC)

ISIC encompasses 21 industry sections

A - Agriculture, forestry and fishing
B - Mining and quarrying
C - Manufacturing
D - Electricity, gas, steam and air conditioning supply
E - Water supply; sewerage, waste management and remediation
F - Construction
G - Wholesale and retail trade; repair of motor vehicles & motorcycles
H - Transportation and storage
I - Accommodation and food service activities
J - Information and communication
K - Financial and insurance activities
L - Real estate activities
M - Professional, scientific and technical activities
N - Administrative and support service activities
O - Public administration and defence; compulsory social security
P - Education
Q - Human health and social work activities
R - Arts, entertainment and recreation
S - Other service activities
T - Activities of households as employers …
U - Activities of extraterritorial organizations and bodies

Example for the ISIC structure

J - Information and communication
… [58 – 62] …
63 - Information service activities
631 - Data processing, hosting and related …; web portals
6311 - Data processing, hosting and related activities
6312 - Web portals
639 - Other information service activities
6391 - News agency activities
6399 - Other information service activities n.e.c.

different uses for VR/AR/MR

ISIC encompasses 21 different industry sections, 88 divisions, 238 groups and 419 classes

Use in this research

To operationalize the analysis along industries their grouping needs to be restructured

- analysis based on 419 classes is impracticable
- use of VR/AR/MR applications do not comply with ISIC industry boundaries
- ISIC names of divisions and groups is not concise

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For this research 41 industries are derived from the ISIC taxonomy

[Deriving Industries] Overview of Derived Industries Analyzed

41 Derived Industries	
Agriculture, Forestry & Fishing Industry	Scientific Research Service Industry
Mining & Quarrying Industry	Advertising Industry
Manufacturing Industry	General Professional Service Activity
Utilities Industry	Employment Service Industry
Construction Industry	Tourism Industry
Automotive Aftermarket	Facility Management Industry
Wholesale Industry	General Adm. & Support Service Activity
Retail Industry	Public Administration
Transportation & Storage Industry	Military and Safety Services
Accommodation & Food Service Industry	Social Security Services
General Publishing Activity	Education Industry
Software Publishing Industry	Health Care Industry
Video Game Industry	Arts & Entertainment Industry
Film Industry	Cultural Heritage Industry
Music Industry	Gambling Industry
Broadcasting Industry	Leisure Facility Industry
Communication and IT Service Industry	Appliance Repair Service Industry
Other Information Service Activity	Other Service Activity
Financial & Insurance Industry	Private Household Activity
Real Estate Industry	Extraterritorial Activity
Architectural & Engineering Service Industry	

The 41 industries represent the "lowest common denominator" of industries

- which are aligned with the ISIC standard
- using a similar set of VR/AR/MR applications

Characteristics of the derived industries

- naming is based either on the ISIC taxonomy or based on established industry designations
- four ISIC levels are reduced to on single layer of industries which is "MECE"

Next four slides show how the industries are derived from ISIC

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Utility Industry combines ISIC sections D and E · Automotive Aftermarket, Wholesale and Retail Trade derive from section G

[Deriving Industries] Defining the Industries used in this Research (1/4)

- ISIC sections A, B and C are directly adopted: *Agriculture, Forestry & Fishing Industry, Mining & Quarrying Industry* and *Manufacturing Industry*
- ISIC sections D and E are combined to *Utilities Industry*: the naming is more concise and VR, AR, and MR applications can be used in similar ways in these industries
- ISIC section F is directly adopted: *Construction Industry*
- ISIC section G is split into *Automotive Aftermarket*, *Wholesale Industry* and *Retail Industry*

Industry Section	Subdivision	Defined Industry
A - Agriculture, forestry and fishing		Agriculture, Forestry & Fishing Industry
B - Mining and quarrying		Mining & Quarrying Industry
C - Manufacturing		Manufacturing Industry
D - Electricity, gas, steam and air conditioning supply E - Water supply; sewerage, waste management and remediation activities		Utilities Industry
F - Construction		Construction Industry
G - Wholesale and retail trade; repair of motor vehicles and motorcycles	[G.452] Maintenance and repair of motor vehicles [G.453] Sale of motor vehicle parts and accessories [G.454] (Maintenance and repair of motorcycles and parts)	Automotive Aftermarket
	[G.46] Wholesale trade, except of motor vehicles and motorcycles [G.451] Sale of motor vehicles (Wholesale) [G.454] (Sale of motorcycles) (Wholesale)	Wholesale Industry
	[G.47] Retail trade, except of motor vehicles and motorcycles [G.451] Sale of motor vehicles (Retail) [G.454] (Sale of motorcycles) (Retail)	Retail Industry

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ISIC section J - Information and Communication is split into ten distinct industries

[Deriving Industries] Defining the Industries used in this Research (2/4)

- ISIC sections H and I are directly adopted: *Transport. & Storage* and *Accom. & Food Service Industry*
- In ISIC section J, *Publishing activities* are split into *General Publishing Activities*, *Software Publishing Industry* and *Video Game Industry* as the usage of VR, AR, and MR applications in these industries differs largely
- *Film Industry, Music Industry, Broadcasting Industry, Communication and IT Service Industry,* and *Other Information Service Activity* derive from ISIC section J
- ISIC sections K and L are directly adopted: *Financial & Insurance Industry* and *Real Estate Industry*

Industry Section	Subdivision	Defined Industry
H - Transportation and storage		Transportation & Storage Industry
I - Accommodation and food service activities		Accommodation & Food Service Industry
J - Information and communication	[J.581] Publishing of books, periodicals and other publishing activ.	General Publishing Activity
	[J.582] Software publishing (Application/Systems Software)	Software Publishing Industry
	[J.582] Software publishing (Games Software)	Video Game Industry
	[J.591] Motion picture, video and television programme activities	Film Industry
	[J.592] Sound recording and music publishing activities	Music Industry
	[J.60] Programming and broadcasting activities	Broadcasting Industry
	[J.61] Telecommunication activities	
	[J.62] Computer programming, consultancy and related activities	Communication and IT Service Industry
	[J.631] Data processing, hosting and related activities; web portals	
	[J.639] Other information service activities	Other Information Service Activity
K - Financial and insurance activities		Financial & Insurance Industry
L - Real estate activities		Real Estate Industry

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The Advertising Industry derives from ISIC section M · The Tourism Industry can be found in ISIC section N

[Deriving Industries] Defining the Industries used in this Research (3/4)

- ISIC section M is split into four industries: *Architectural & Engineering Service Industry, Scientific Research Service Industry, Advertising Industry* and *General Professional Service Activity*
- ISIC section N is split into four industries: *Employment Service Industry, Tourism Industry, Facility Management Industry* and *General Administrative & Support Service Activity*

Industry Section	Subdivision	Defined Industry
M - Professional, scientific and technical activities	[M.71] Architectural and engineering activities [M.72] Scientific research and development [M.73] Advertising and market research	Architectural & Engineering Service Industry Scientific Research Service Industry Advertising Industry
	[M.69] Legal and accounting activities [M.70] Activities of head offices; management consultancy activities [M.74] Other professional, scientific and technical activities [M.75] Veterinary activities	General Professional Service Activity
N - Administrative and support service activities	[N.78] Employment activities [N.79] Travel agency, tour operator, reservation service and related [N.81] Services to buildings and landscape activities	Employment Service Industry Tourism Industry Facility Management Industry
	[N.77] Rental and leasing activities [N.80] Security and investigation activities [N.82] Office admin., office support and other business support	General Administrative & Support Service Activity

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ISIC section R contains the Gambling and Leisure Facility Industry · Repair of household appliances can be found in S

[Deriving Industries] Defining the Industries used in this Research (4/4)

- ISIC section O includes activities of a governmental nature · The section is split into *Public Administration, Military and Safety Services* and *Social Security Services*
- ISIC sections P and Q are directly adopted: *Education Industry* and *Health Care Industry*
- ISIC section R is split into four industries: *Arts & Entertainment Industry, Cultural Heritage Industry, Gambling Industry* and *Leisure Facility Industry*
- ISIC section S is split into two industries: *Appliance Repair Service Industry* and *Other Service Activity*
- ISIC sections T and U are directly adopted: *Private Household Activity* and *Extraterritorial Activity*

Industry Section	Subdivision	Defined Industry
O - Public admin. and defence; compulsory social security	[O.841] Administration of the State and the econ. and social policy	Public Administration
	[O.842] Provision of services to the community as a whole	Military and Safety Services
	[O.843] Compulsory social security activities	Social Security Services
P - Education		Education Industry
Q - Human health and social work activities		Health Care Industry
R - Arts, entertainment and recreation	90 - Creative, arts and entertainment activities	Arts & Entertainment Industry
	91 - Libraries, archives, museums and other cultural activities	Cultural Heritage Industry
	92 - Gambling and betting activities	Gambling Industry
	93 - Sports activities and amusement and recreation activities	Leisure Facility Industry
S - Other service activities	95 - Repair of computers and personal and household goods	Appliance Repair Service Industry
	94 - Activities of membership organizations 96 - Other personal service activities	Other Service Activity
T - Activities of households as employers; undifferentiated goods- and services-producing		Private Household Activity
U - Activities of extraterritorial organizations and bodies		Extraterritorial Activity

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The venture activity was measured by identifying the client facing product offering of 1654 VR/AR/MR startups

[Measuring Venture Activity] Identifying VR/AR/MR Activities in Industries

Initial Data Source

The analysis was conducted on CrunchBase which is a global database that provides information on venture capital and startup activities.

On June 15, 2017, we conducted a search query on CrunchBase for the keywords “Virtual Reality”, “Augmented Reality”, “Mixed Reality”, and/or “Extended Reality”. The search yielded 2,093 results/companies.

Research Approach

For each company (1) the respective company website (2) was opened. We checked (3), if the website was reachable and the company in fact operated in the field of VR/AR/MR. For all true-positives, we identified for which industries these companies create products for. Companies were tagged with up to 5 ISIC codes (4).

Excerpt from the Documentation

Descriptive Statistics

- **2093** company websites were searched for, opened and analyzed
- **275 (13.1%)** of websites were not reachable, discontinued or not findable
- **164 (7.6%)** were false positives (they did not deal with VR/AR technology)
- **1654 (79.2%)** of companies were tagged by the client facing prod. offering according to ISIC
- **3154** tags were assigned with an average of **1.9** tags per company
- To achieve an equal weighting, each company has a total vote of 1
- After the analysis according to ISIC the tags were aggregated into the derived industries

1		4					3			2	
	A	B	C	D	E	F	G	M	N	P	U
1	Company Name	indu	indus	indus	indus	indus	Validatic	Founded	Closed D	Website	Country
1500	SmartGurIz A/S	8510	5821				WAHR	09.11.2014		http://www.	United State
1501	Dekko						not reachab	31.12.2010		http://www.	United State
1502	Parrot						FALSCH	31.12.1993		http://www.	France
1503	Proxy42 Inc	5821	3240	2640			WAHR	02.07.2012		http://fathe	United State
1504	HomeSpotter	6010	6020	6190			WAHR	31.12.2008		http://home	United State
1505	Augmedics	3250	8620				WAHR	31.12.2013		http://www.	Israel
1506	LightUp	8510	8549	3240	5821		WAHR	31.12.2012		http://www.	United State

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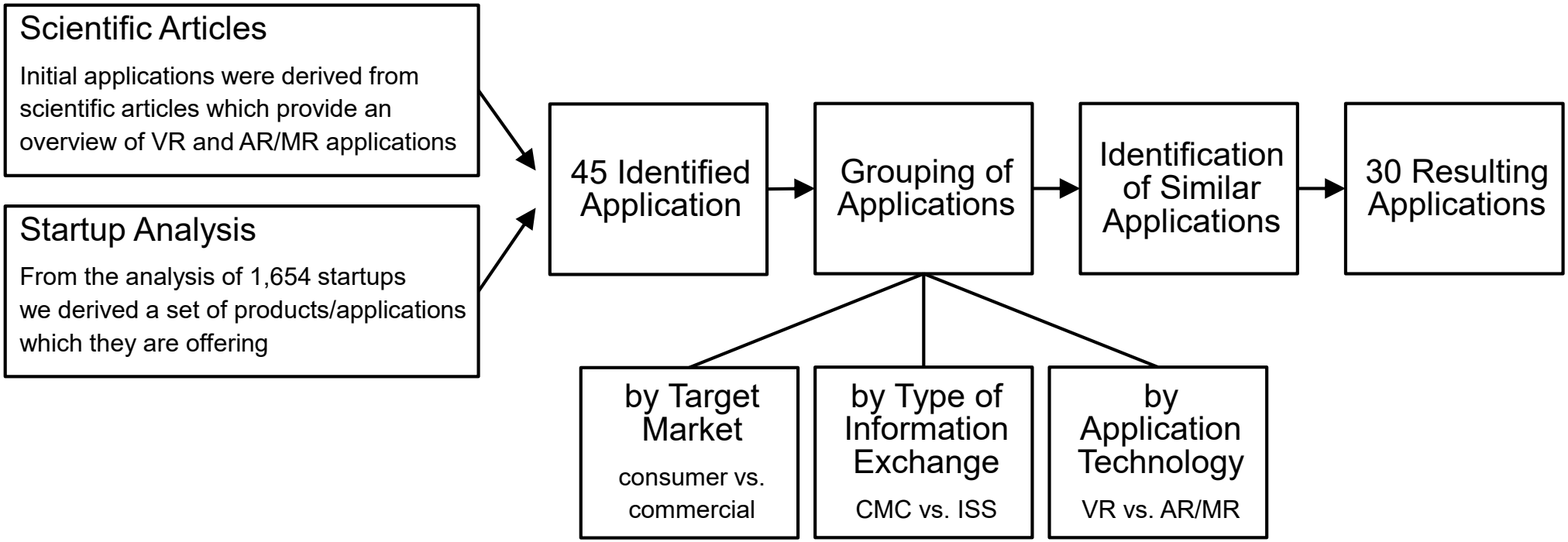
30 VR/AR/MR applications were identified from scientific articles and the startup analysis

[Application Identification] Process of Application Identification

A list of 45 applications was derived from scientific articles and the startup analysis. The applications were grouped by target market, type of information exchange and application technology in a total of 8 distinct groups. In each group, similar applications were identified and merged. In total, 30 applications resulted from the identification process.

Flowchart of the Application Identification Process



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From eight major theories on innovation adoption, five innovation characteristics were derived for this research

[Evaluating Hardware & Applications] Deriving Innovation Characteristics

Theory on Innovation Adoption \ Derived Innovation Characteristics	Performance / Pay-Off	Complexity / Cost	Compatibility / Fit	Cognitive Absorption	Facilitating Conditions	
Theory of Reasoned Action			■			(Fishbein & Ajzen, 1975)
Technology Acceptance Model	■	■	■			(Davis, 1989)
Motivational Model	■			■		(Davis, Bagozzi & Warshaw, 1992)
Theory of Planned Behaviour		■	■			(Ajzen, 1991; Taylor & Todd, 1995)
Model of PC Utilization	■	■	■	■	■	(Thompson, Higgins & Howell, 1991)
Innovation Diffusion Theory	■	■	■		■	(Moore & Benbasat, 1991)
Social Cognitive Theory	■	■		■		(Compeau & Higgins, 1995)
Unified Theory of Acceptance and Use of Technology	■	■	■		■	(Venkatesh, Morris, Davis & Davis, 2003)

Innovation characteristics are used in this research to evaluate innovations

- Characteristics are measured based on a qualitative analysis
- Characteristics are measured across multiple levels of analysis

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■ Construct not used in theory
■ Construct used in theory

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Qualitative Interviews, Conference Talks and Newspaper Articles are used to obtain information on innovation characteristics

[Evaluating Hardware & Applications] Information Sources for Innovation Evaluation

Information Sources

Qualitative Interviews

15 unstructured interviews
with VR/AR/MR experts
29.65 minutes each

Recorded Conference Talks

17 conference talks of VR/AR/MR experts
held at major VR/AR/MR conferences
recorded and published on YouTube

News Coverage

86 newspaper articles analyzed
information on VR and AR/MR applications
published by reputable news magazines

Innovation Characteristics

Performance / Pay-Off	relative advantage · positive outcomes · usefulness · etc.
Complexity / Cost	adoption cost · implementation effort · complexity of use · etc.
Compatibility / Fit	social norms · existing environment · established processes · etc.
Cognitive Absorption	positive psychological state · usability · immersiveness · motivation · etc.
Facilitating Conditions	complementary technologies · network externalities · etc.

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15 interviews were used for evaluating VR/AR/MR hardware and applications regarding innovation characteristics

[Evaluating Hardware & Applications] Qualitative Interviews

In total, 18 interviews were conducted between July 31, 2017 and October 19, 2017. For the further analysis 15 interviews were used, transcribed and coded in MaxQDA. With one exception participants allowed us to use their real name for publication. In total, we recorded 444:44 min of audio material. Each interview had an average length of 29.65 min.

Name	Position	Company
Jacobo Cabaleiro	Senior Software Engineer	Microsoft
Peder Børresen	CEO	HoloCap
Christina Kinne-Pat	Evangelist	High-Fidelity
Georg Baier	Business Analyst	Remote Control Productions
Astrid Kahmke	Creative Director	Bavarian Film Center
Stefan Göppel	Business Development	Re'flekt 360
Paula Monteiro	Marketing Director	Wikitude
Nicola Radacher	VP Operations	Wikitude
Arne Schönleben	CEO	Innovation.Rocks
Stefan Seidl	CEO	Innoactive
Helmut Guggenbichler	CEO	Augmensys
Malte Hedemann	Head of Digital Realities	Volkswagen
<Consultant>	Senior Manager	<Major Consultancy>
Enrico Kürtös	CEO	Inreal Technologies
Michaela Fraundorfer	Sales Director	Roomle

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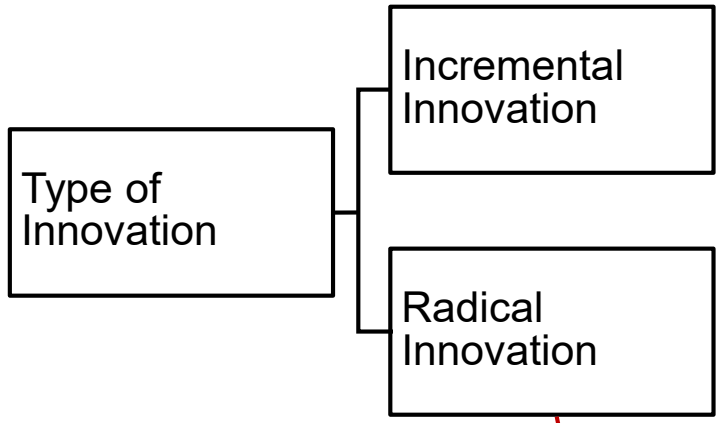
Depending on the particular industry, innovations can be radical and trigger a process of industrial change

[Assessing the Impact on Industries] Measuring the Radicalness of Innovations

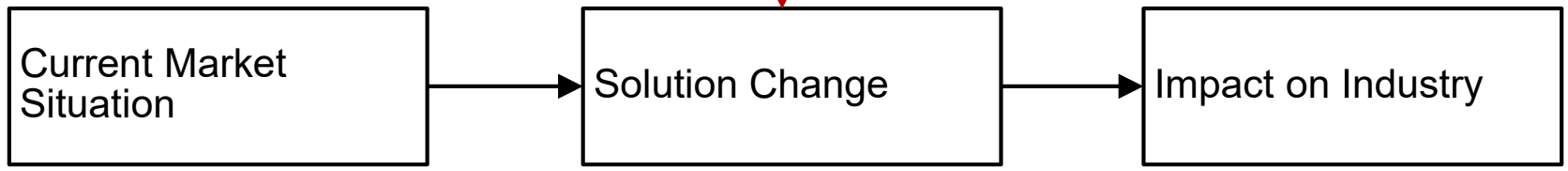
How can the impact of an innovation be assessed?



Applying an innovation to a particular industry represents ***no*** **major departure from existing practices**

Applying an innovation to a particular industry represents a **major departure from existing practices**

How do industries change?



Outlines preconditions and the current market situation of the industry which might be subject to change

Outlines how current solutions (products or processes) might be substituted by VR/AR/MR-enabled radical solutions

Outlines an industrial change scenario, which shows the implications of the solution change on the industry

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For each of the 30 VR and AR/MR applications the effect on all 41 industries is assessed

[Assessing the Impact on Industries] Application on Industry Matching (Excerpt)

Industries

Applications

Agriculture, Forestry & Fishing Industry
Mining & Quarrying Industry
Manufacturing Industry
Utilities Industry
Construction Industry
Automotive Aftermarket
Wholesale Industry
Retail Industry

… (41 industries) …

… (30 VR/AR/MR applications) …

VR Telepresence

VR Engineering

Medical Visualization

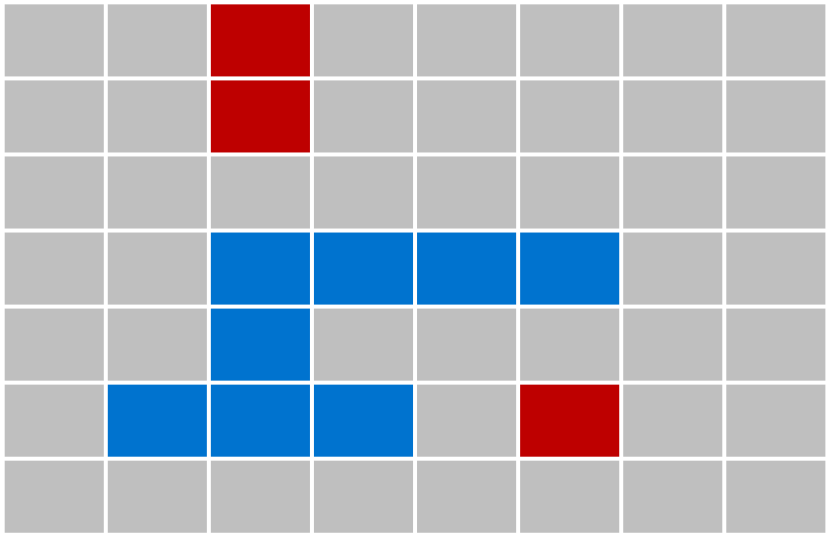
Remote Support

Mixed Reality Meeting

VR Simulator

Immersive Therapy

… (30 VR/AR/MR applications) …



The effect on each industry is assessed by identifying whether the application has:

- no effect
- incremental effect
- radical effect

Appendix B: Derivation of all 41 industries
Appendix C: Description of all Applications

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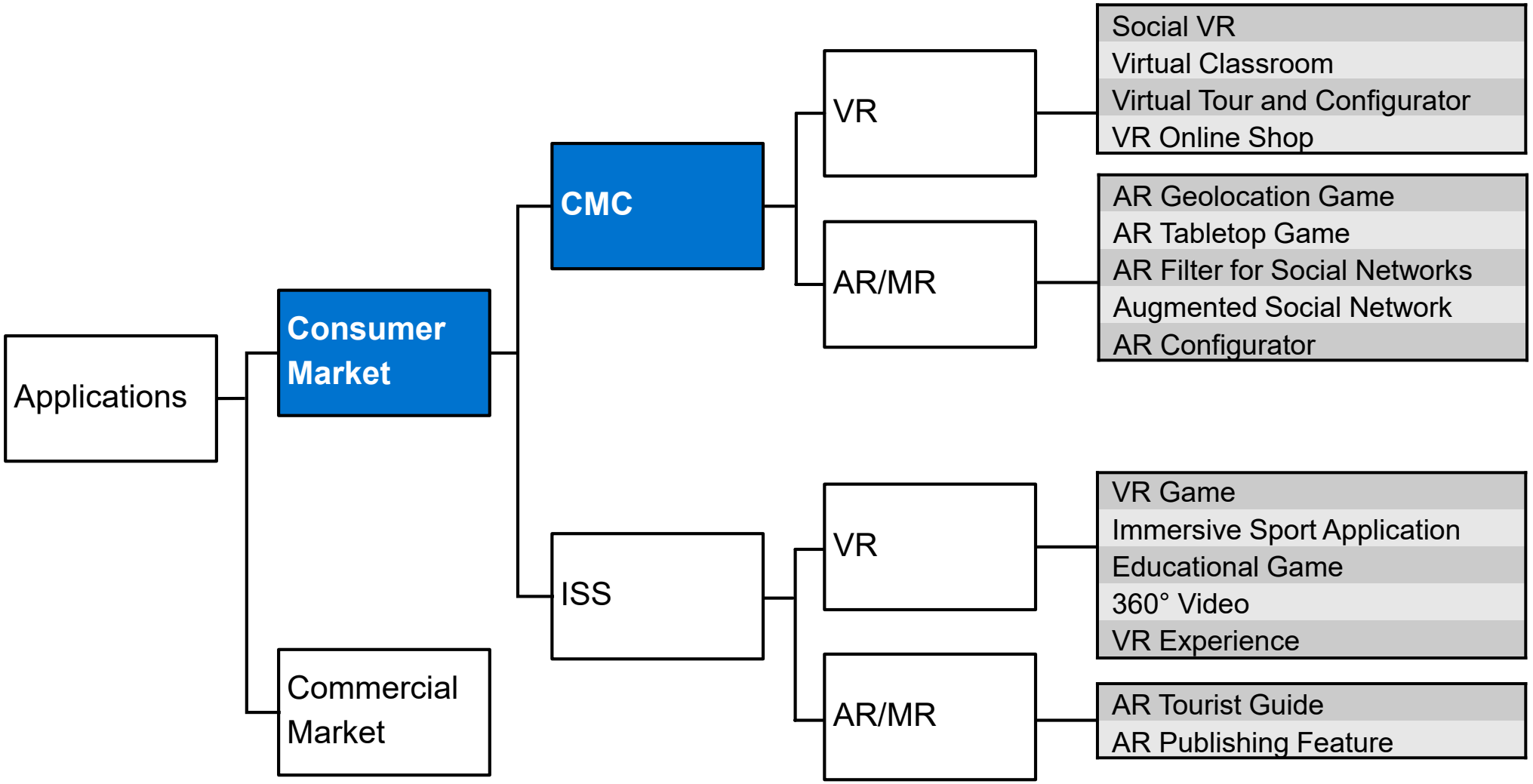
Impact of Virtual, Mixed, and Augmented Reality on Industries

Appendix

DOI: 10.14459/2018md1454069

Impact of Virtual, Mixed and Augmented Reality on Industries

Appendix C (1/4)



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Social VR allows users to spend quality time with others through being immersed into a variety of shared activities

Social VR

Description & Example

In virtual environments, users can meet other users in VR and talk face-to-face

Potential activities are:

- meeting in specific locations
- building virtual environments together
- playing VR games

Note. Still from the Social Network Rec Room. The still exemplifies the importance of providing shared activities to users. Source. Against Gravity (2017).

Innovation Characteristics & Evaluation

Primary Substitute: Video Chat

Performance/Pay-Off	+ spend quality time with friends + mini-games offer shared experiences
Complexity/Cost	*(not affected)*
Compatibility/Fit	- don a headset before communication - low social approval of headsets in public
Cognitive Absorption	+ face-to-face communication
Facilitating Conditions	- dependent on network effects

Diffusion Period: 2020-2030 Saturation Level: high

Impacted Industries (in order of occurrence)

- Video Game Industry
- Leisure Facility Industry
- Communication and IT Service Industry
- Gambling Industry

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Virtual Classrooms allow educators to deliver educational content in new and engaging ways over a distance

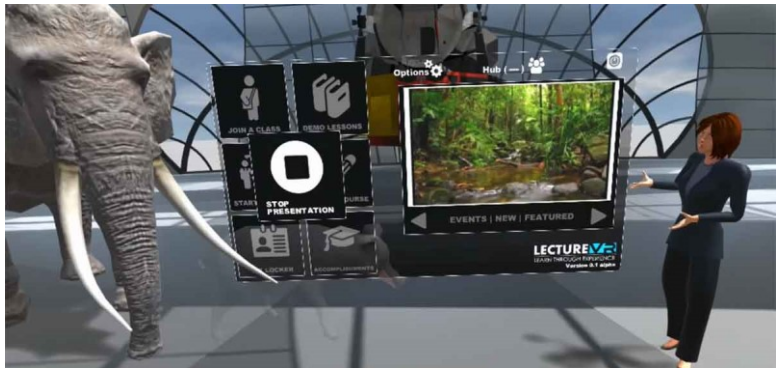
Virtual Classroom

Description & Example

Educators can deliver immersive education to students

Special capabilities of Virtual Classrooms:

- visualization of 3D objects
- distance education
- interconnection with VR tours



Note. Still from the educational platform LectureVR. The still exemplifies the possibility of integrating different formats in VR such as: virtual environments, presentations, film, 3D objects. Source. Virtual Reality For Education (2016).

Innovation Characteristics & Evaluation

Primary Substitute: Lecture Recording

Performance/Pay-Off	+ higher learning effect + visualizations in 3D space
Complexity/Cost	- production of 3D content can be expensive
Compatibility/Fit	+ modern types of education - don a headset
Cognitive Absorption	+ increased immersion and motivation + face-to-face communication
Facilitating Conditions	- lack of peripheral equipment for work - educators lack skills to create content

Diffusion Period: 2020-2030 Saturation Level: high

Impacted Industries (in order of occurrence)

- Education Industry

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Virtual Tours and Configurators allow immersive visualization and configuration of products and projects

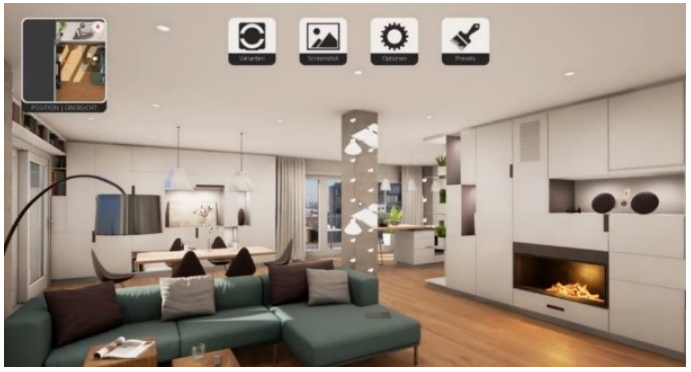
Virtual Tour and Configurator

Description & Example

Product and project visualizations are made accessible and configurable

Can help in all domains, in which products are complex and vary in configuration:

- real estate projects
- cars
- apparel and fashion items



Note. Still from Inreal Technology's Virtual 3D Walkthrough. The still exemplifies how virtual tours and configurators increase the imaginability of projects and products and allow for configuration changes. Source. Inreal Technology (2017).

Innovation Characteristics & Evaluation

Primary Substitute: Visualization

Performance/Pay-Off	+ improved customer communication
	+ increased conversion rates
Complexity/Cost	+ reduced prototyping/customization cost
	- availability of 3D data
Compatibility/Fit	+ backend integration increases efficiency
Cognitive Absorption	+ enhanced imaginability
Facilitating Conditions	+ customers expect more information
	+ customers want to make choices

Diffusion Period: 2020-2030 Saturation Level: high

Impacted Industries (in order of occurrence)

- Retail Industry
- Real Estate Industry
- General Adm. & Support Service Activity
- Architectural & Engineering Service Industry

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VR Online Shops increase customer engagement by discovering products and providing support in new ways

VR Online Shop

Description & Example

Customers can discover products in virtual environments in new ways

- life-size visualizations of products
- discovering products in new ways
- customer service in VR
- shopping with friends
- view different product alternatives

Note. Still from Alibaba's Buy+ VR shop. The still exemplifies how the online shopping experience can be transformed though VR. Customer service representatives can advise users in VR. Source. Alibaba Group (2016).

Innovation Characteristics & Evaluation

Primary Substitute: Conventional Online Shop

Performance/Pay-Off	+ increased conversion rates
Complexity/Cost	+ reduced return deliveries - availability of 3D data
Compatibility/Fit	+ new ways of providing customer service
Cognitive Absorption	+ enhanced imaginability
Facilitating Conditions	- high effort of modelling assortment in 3D

Diffusion Period: 2020-2030 Saturation Level: high

Impacted Industries (in order of occurrence)

- Retail Industry
- Financial & Insurance Activity
- General Professional Service Activity

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AR Geolocation Games allow users to play entertaining out-of-home games in groups

AR Geolocation Game

Description & Example

Users play the online game out-of-home · Content and events are defined by the user's location

A subcategory of AR geolocation games are AR shooting games in which users try to defeat virtual enemies or other players

Outdoor activities can be used for sport applications

Note. Still from Pokémon Go. Creatures from the Pokémon saga are superimposed on the player's smartphone camera image. The player can try to capture those creature. Source. Meedia (2016).

Innovation Characteristics & Evaluation

Primary Substitute: Laser Tag

Performance/Pay-Off	+ entertainment value
Complexity/Cost	*(not affected)*
Compatibility/Fit	+ outdoor activity - low social approval of playing in public
Cognitive Absorption	+ multiplayer game
Facilitating Conditions	- narrow field-of-view (handheld devices) - device robustness (headset devices)

Diffusion Period: 2030-2040 Saturation Level: medium

Impacted Industries (in order of occurrence)

- Video Game Industry

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AR Tabletop Games allow new types of games in which online and offline game elements are combined in new ways

AR Tabletop Game

Description & Example

The surface of an empty table, a game board or playing card is augmented with virtual objects

Conventional trading cards, board games and online smartphone games can be combined in new ways

Note. Still from Augmentors. Creatures battle against each other. The still exemplifies the combination of online and offline games. Source. Augmentors Games (2016).

Innovation Characteristics & Evaluation

Primary Substitute: Board Game

Performance/Pay-Off	+ increased sales figures tough selling game via online and offline sales channels
Complexity/Cost	*(not affected)*
Compatibility/Fit	+ appealing features to young generation - low social approval for board games
Cognitive Absorption	+ visualization of game events
Facilitating Conditions	- not hands-free and narrow field-of-view (handheld devices)

Diffusion Period: 2030-2040 Saturation Level: low

Impacted Industries (in order of occurrence)

- Video Game Industry

DOI: 10.14459/2018md1454069

AR Filters increase user engagement and serve as an advertising format on social networks

AR Filter for Social Networks

Description & Example

AR Filters alter facial expressions or add digital elements to photos and videos

As of 2017, AR Filters have wide diffusion on Social Networks such as Facebook or Snapchat

Note. Examples for AR Filters on Snapchat. The images show how AR Filters can be used both as a communication and as an advertising feature. Source. Sloane (2017).

Innovation Characteristics & Evaluation

Primary Substitute: Unfiltered Photo/Video

Performance/Pay-Off	+ increased engagement of users
Complexity/Cost	+ viral advertising requires less expenditure
Compatibility/Fit	+ more casual/spontaneous interactions
Cognitive Absorption	+ more engaging interactions
Facilitating Conditions	- only for some forms of interaction - only for some user groups

Diffusion Period: 2020-2030 Saturation Level: high

Impacted Industries (in order of occurrence)

- Communication and IT Service Industry
- Advertising Industry

DOI: 10.14459/2018md1454069

Augmented Social Networks can provide users with information on their surroundings and on other participants of the network

Augmented Social Network

Description & Example

Location- and user-based information can be superimposed in the user's field-of-view

Although still in a conceptional stage they could help users obtain information on:

- other private individuals in public spaces
- other professionals at trade fairs
- special offers of near by stores

Note. Figure illustrates how augmented social networks could look like in the future. Augmented social networks are still in a conceptual stage as they are highly dependent on mature hardware devices. Source. Ridden (2010).

Innovation Characteristics & Evaluation

Primary Substitute: Conventional Social Network

Performance/Pay-Off	+ information on users and environment + mixed reality telepresence features
Complexity/Cost	*(not affected)*
Compatibility/Fit	+ integration with games, tourist guides, etc. - privacy issues incompatible with legislation - social approval of headsets in public
Cognitive Absorption	+ integration with other apps can be immersive
Facilitating Conditions	- dependent on high-end consumer AR headsets preferably usable outdoors

Diffusion Period: 2020-2030 Saturation Level: high

Impacted Industries (in order of occurrence)

- Communication and IT Service Industry
- Advertising Industry
- Tourism Industry
- General Professional Service Activity

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AR Configurators increase the imaginability of products for customers

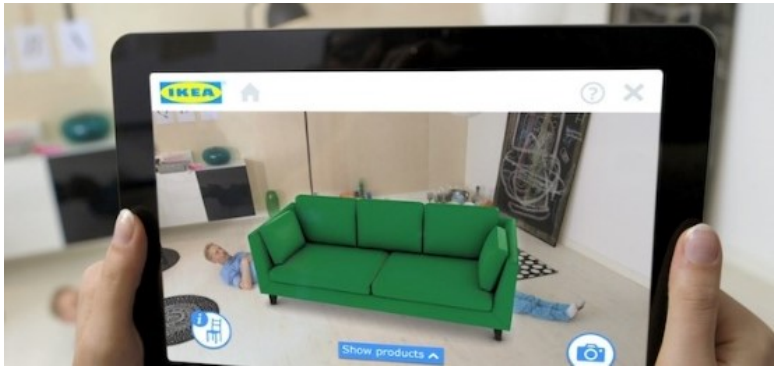
AR Configurator

Description & Example

Customers can visualize and configure product items in the intended position

Increase the imaginability of how:

- products look in life-size
- different product configurations look
- products fit into the environment



Note. Still of IKEA places. The still exemplifies how users can augment furniture objects into their home living space. The AR app is available on tablets and smartphones. Source. Stinson (2013).

Innovation Characteristics & Evaluation

Primary Substitute: Advice at Bricks-and-Mortar Store

Performance/Pay-Off	+ increased conversion rates
Complexity/Cost	- availability of 3D data
Compatibility/Fit	+ no need to take measurements + share configurations with friends
Cognitive Absorption	+ enhanced imaginability + flexibility in trying different configurations
Facilitating Conditions	+ effective use on handheld devices - digitalize assortment across value chain

Diffusion Period: 2020-2030 Saturation Level: high

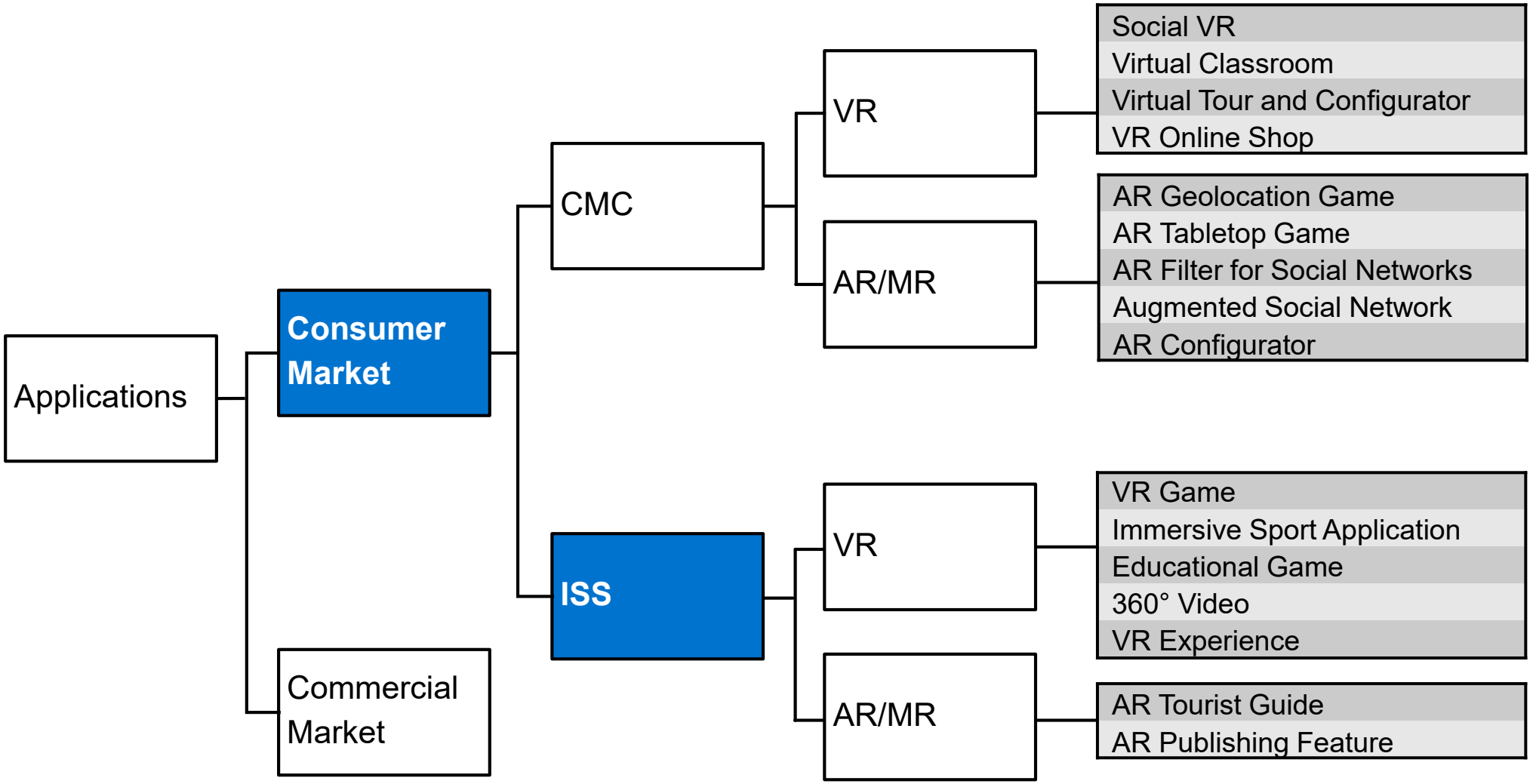
Impacted Industries (in order of occurrence)

- Retail Industry
- Real Estate Industry

DOI: 10.14459/2018md1454069

Impact of Virtual, Mixed, and Augmented Reality on Industries

Appendix C (2/4)



DOI: 10.14459/2018md1454069

VR Games allow players to fully immerse in game scenes and have an intensified gaming experience

VR Game

Description & Example

VR Games allow players to experience action scenes in a more immersive way

High immersion is triggered through:

- full 360° view
- 3D visualization
- full body-tracking

Note. Still from Marvel Avengers for Oculus Rift. The still exemplifies the immersiveness of VR games. Users can experience game scenes and game characters in life-size. Source. James (2017).

Innovation Characteristics & Evaluation

Primary Substitute: Conventional PC/Console Game

Performance/Pay-Off	+ new types of experiences - slower reaction times
Complexity/Cost	*(not affected)*
Compatibility/Fit	- space requirements at home - not applicable to all types of games
Cognitive Absorption	+ more immersive gaming experience + facial expressions in multi-player games
Facilitating Conditions	- peripheral equipment might be required

Diffusion Period: 2020-2030 Saturation Level: high

Impacted Industries (in order of occurrence)

- Games Industry
- Arcade Industry

DOI: 10.14459/2018md1454069

Immersive Sport Applications provide highly immersive workout experiences to users

Immersive Sport Application

Description & Example

Users experience game-like environments in VR that require extensive body-movement

Immersive Sport Applications are frequently tailored to different kinds of treadmills

Note. Still from Icaros, a VR sport equipment and flight simulator. The still exemplifies how VR can be used to provide more immersive workout experiences. Source. Icaros flight (2016).

Innovation Characteristics & Evaluation

Primary Substitute: Conventional Sport Equipment

Performance/Pay-Off	+ higher total effect of workout
Complexity/Cost	- expensive peripheral hardware equipment
Compatibility/Fit	- space requirements of peripheral hardware - social acceptance of using VR for sport - perspiration during workout
Cognitive Absorption	+ motivation through immersiveness + motivation through simulating competition
Facilitating Conditions	*(not affected)*

Diffusion Period: 2020-2030 Saturation Level: low

Impacted Industries (in order of occurrence)

- Video Game Industry
- Leisure Facility Industry

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Educational Games allow users to acquire learning content in a more immersive way

Educational Game

Description & Example

In virtual environments, users can acquire learning content in an immersive way

High learning effect through:

- Visual and immersive content delivery
- Optimizing tutoring though AI
- Situated learning

Note. Still from InMind VR 2, an application that allows players to explore brain chemistry and neurobiology. The still exemplifies how educational content can be gamified and improve learning effect of students. Source. Maximumandroid (2016).

Innovation Characteristics & Evaluation

Primary Substitute: Conventional Educational Game

Performance/Pay-Off	+ increased learning and retention rate
Complexity/Cost	- expensive to create content
Compatibility/Fit	+ visualizations of learning content - ambivalent reputation of game publishers - lack of alignment with national curriculum
Cognitive Absorption	+ higher immersiveness + gamification increases motivation
Facilitating Conditions	+ parents might endorse children's usage - single-topic game hard to market

Diffusion Period: 2020-2030 Saturation Level: medium

Impacted Industries (in order of occurrence)

- Video Game Industry
- Education Industry

DOI: 10.14459/2018md1454069

360° Videos elicit high levels of immersion in audiences

360° Video

Description & Example

360° cameras record scenes in all directions · The viewer can experience full immersion in the scene

Note. 360° still viewable on Gear VR. The still exemplifies viewers can immerse into film scene and perceive the environment in new ways. Source. James (2014).

Innovation Characteristics & Evaluation

Primary Substitute: Conventional Video

Performance/Pay-Off	+ new kind of user experience
Complexity/Cost	+ in general production costs increase only slightly (other than with VR Experiences)
Compatibility/Fit	- inhibited cinematography (e.g. close-ups)
Cognitive Absorption	+ high levels of immersion
Facilitating Conditions	+ camera devices available for consumers - might not enter mainstream cinema

Diffusion Period: 2020-2030 Saturation Level: low

Impacted Industries (in order of occurrence)

- Film Industry
- Music Industry
- Broadcasting Industry
- Advertising Industry
- Tourism Industry
- Education Industry
- Arts & Entertainment Industry
- Cultural Heritage Industry

DOI: 10.14459/2018md1454069

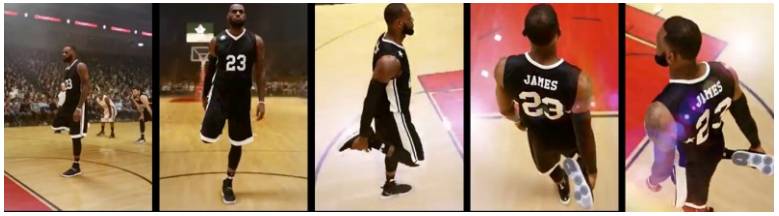
VR Experiences allow users to explore a virtual or digitalized environment

VR Experience

Description & Example

Users can move around in a completely virtual or digitalized (real) environment

While current VR Experiences are closely related to VR Games, future experiences might blend virtual and real environments seamlessly together through technologies such as volumetric capturing



Note. Still from Intel True VR. The volumetric capturing technology allows viewers to perceive video scenes form any angle. The still exemplifies how VR could change the consumption of sport or music events. Source. Lee (2017).

Innovation Characteristics & Evaluation

Primary Substitute:

Performance/Pay-Off	+ new user experience
Complexity/Cost	- high production costs - expensive camera equipment
Compatibility/Fit	- lack of social aspects (e.g. with friends)
Cognitive Absorption	+ high levels of immersion
Facilitating Conditions	- requires high adoption of VR devices on the market for projects to be profitable

Diffusion Period: 2020-2030 Saturation Level: medium

Impacted Industries (in order of occurrence)

- Video Game Industry
- Film Industry
- Music Industry
- Broadcasting Industry
- Communication and IT Service Industry
- Cultural Heritage Industry
- Tourism Industry
- Education Industry
- Arts & Entertainment Industry

DOI: 10.14459/2018md1454069

AR Tourist Guides superimpose location-based information for visitors of cities, cultural heritage sites or museums

AR Tourist Guide

Description & Example

AR Tourist guides allow users to obtain information on the objects in their close surroundings

Based on the users location and the object in front of the camera object, information is superimposed

Note. Still of the Wikitude App. The application recognizes objects such as the Brandenburg Gate (Berlin, Germany) and display related information. Source. Manager-Magazin (2013).

Innovation Characteristics & Evaluation

Primary Substitute: Travel Guide Book

Performance/Pay-Off	+ instant information for tourists + digitalized tourist guide
Complexity/Cost	+ low-cost consumer-created content
Compatibility/Fit	- requires wearing a headset outdoors
Cognitive Absorption	+ immersive information in field-of-view
Facilitating Conditions	- dependent on high-end consumer AR headsets preferably useable outdoors

Diffusion Period: 2030-2040 Saturation Level: high

Impacted Industries (in order of occurrence)

- Tourism Industry
- Cultural Heritage Industry

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AR Publishing Features provide readers of printed books, magazines and advertisements with additional information

AR Publishing Feature

Description & Example

The surface of printed document is augmented with virtual objects

Augmented publications can be used for:

- newspaper content
- newspaper advertisements
- product catalogs
- school books

Note. Still from the LEGO catalog AR app. The still exemplifies how users can look at 3D models of objects. Source. Ariplay (2015).

Innovation Characteristics & Evaluation

Primary Substitute: Newspaper without AR Feature

Performance/Pay-Off	+ more information for users + new advertisement placement
Complexity/Cost	+ including AR content in newspapers is straightforward and not too cost intensive
Compatibility/Fit	+ other media formats are included in print
Cognitive Absorption	+ increased user engagement
Facilitating Conditions	- dependent on consumer AR headsets

Diffusion Period: 2030-2040 Saturation Level: low

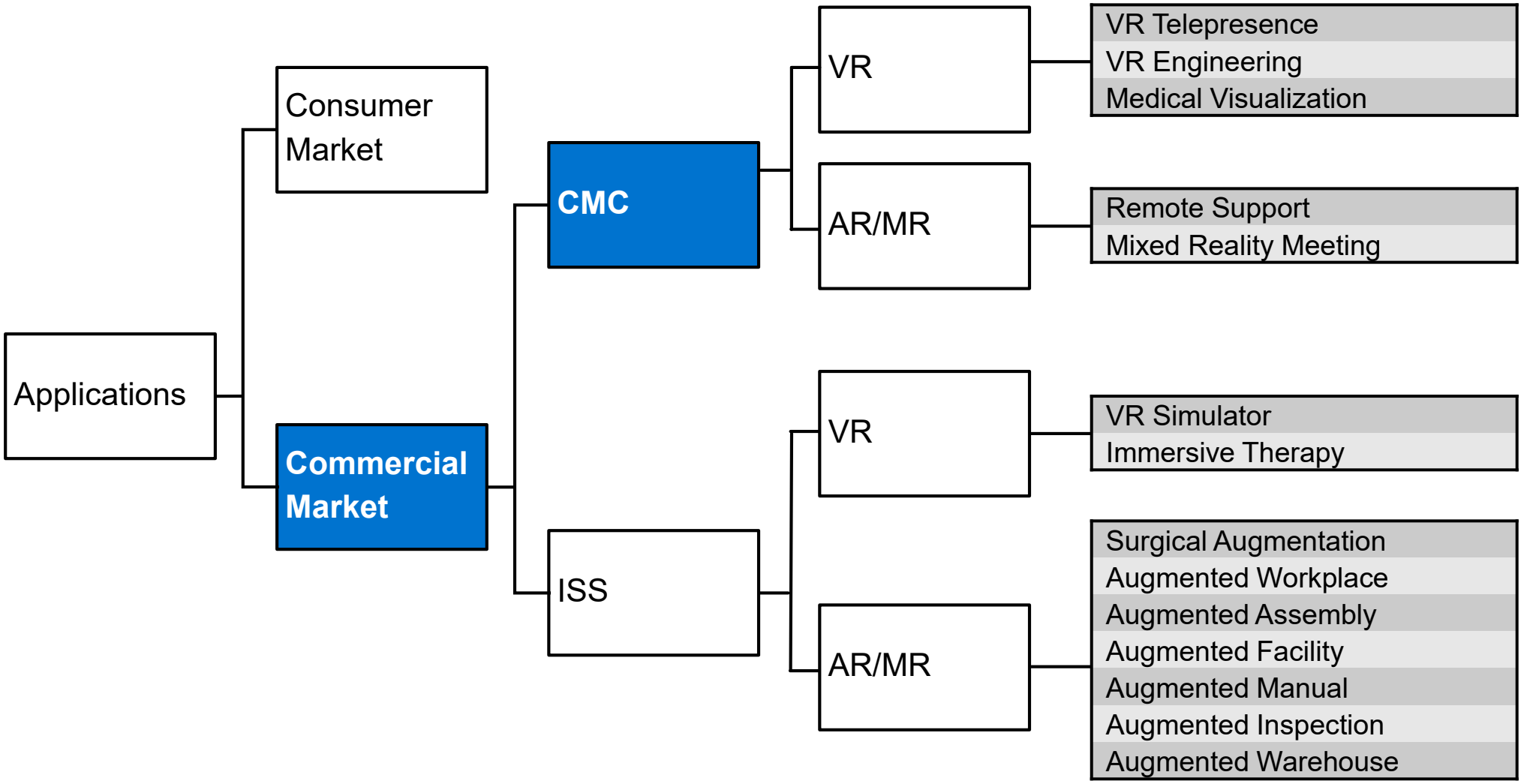
Impacted Industries (in order of occurrence)

- General Publishing Activity
- Advertising Industry
- Education Industry

DOI: 10.14459/2018md1454069

Impact of Virtual, Mixed, and Augmented Reality on Industries

Appendix C (3/4)



DOI: 10.14459/2018md1454069

VR Telepresence allows employees to meet face-to-face in a virtual environment and go about design and planning tasks

VR Telepresence

Description & Example

Employees can collaborate in virtual environments and use virtual objects for enhanced communication

Note. Still from Innoactive Hub. The still exemplifies how employees can collaborate in virtual environments. Communication can be improved though the use of virtual objects. Source. Innoactive GmbH (2017).

Innovation Characteristics & Evaluation

Primary Substitute: Video Chat

Performance/Pay-Off	+ more effective collaboration + discussion can be based on 3D models + increased team cohesion
Complexity/Cost	+ reduction of travel related costs - upfront investment
Compatibility/Fit	- social approval of donning headset at work
Cognitive Absorption	+ fluent face-to-face communication
Facilitating Conditions	+ in line with general digitalization and IT-integration endeavors of companies

Diffusion Period: 2020-2030 Saturation Level: high

Impacted Industries (in order of occurrence)

- Manufacturing Industry
- Employment Service Industry
- Architectural & Engineering Service Industry
- Scientific Research Service Industry

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DOI: 10.14459/2018md1454069

VR Engineering allows engineers, architects, etc. to discuss and test design proposals in VR

VR Engineering

Description & Example

Engineers, architects and other stakeholders can collaborate in virtual environments and improve and test the design of digital models

Note. Still from Nvidia Holodeck. The still exemplifies how users can work on digital prototypes in VR. The system allows detailed work, trying different configurations and simulating assembly processes. Source. Nvidia (2017).

Innovation Characteristics & Evaluation

Primary Substitute: CAVE-System

Performance/Pay-Off	+ increased productivity
	+ avoiding expensive mistakes
Complexity/Cost	+ reduced (physical) prototyping cost
	+ considerably cheaper than CAVE-Systems
Compatibility/Fit	+ location independent collaboration
	+ testing different variations
Cognitive Absorption	+ intuitive understanding of 3D models

Facilitating Conditions - main engineering more effective on PC

Diffusion Period: 2020-2030 Saturation Level: high

Impacted Industries (in order of occurrence)

- Manufacturing Industry
- Architectural & Engineering Service Industry
- Scientific Research Service Industry

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Medical Visualizations allow medical professionals to explore patients' bodies in VR

Medical Visualization

Description & Example

Based on CT images, medical professionals and patients can walk through the patient's body

Note. SNAP (Surgical Navigation Advanced Platform) allows to explore 3D models generated from MRI (Magnetic Resonance Imaging) scans. The illustration exemplifies how surgeons can use VR to prepare for interventions or communicate with patients. Source. Weller (2016).

Innovation Characteristics & Evaluation

Primary Substitute: MRI-Image

Performance/Pay-Off	+ improved quality of surgeries through improved surgeon information
	+ improved communication with patients
Complexity/Cost	+ reduced complexity of surgical procedures through additional information
Compatibility/Fit	+ facilitated pre-surgical planning
	+ patients demand more information
Cognitive Absorption	+ improved patient understanding
Facilitating Conditions	- requires new equipment in hospitals

Diffusion Period: 2020-2030 Saturation Level: medium

Impacted Industries (in order of occurrence)

- Scientific Research Service Industry
- Health Care Industry

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Remote Support enables expedited problem resolution though having experts point at objects in the other person's field-of-view

Remote Support

Description & Example

The receiving partner can transmit the video stream of the AR/MR headset such that the responding partner can point at areas in the receiver's field-of-view

Note. Illustration of usage scenario of Skype for HoloLens. Right: Expert draws into the field of view of the communication partner. Left: Visualization of what the communication sees through the AR device. Illustration exemplifies how Remote Support can facilitate communication. Source. Microsoft (2016).

Innovation Characteristics & Evaluation

Primary Substitute: Telephony

Performance/Pay-Off	+ reduction of downtimes + improved communication
Complexity/Cost	+ reduction of travel related costs
Compatibility/Fit	+ can be readily integrated in other commercial applications
Cognitive Absorption	+ fluent mutual understanding
Facilitating Conditions	- ineffective handling with handheld AR - only necessary for some use cases

Diffusion Period: 2020-2030 Saturation Level: high

Impacted Industries (in order of occurrence)

- Manufacturing Industry
- Utilities Industry
- Construction Industry
- Automotive Aftermarket
- Health Care Industry

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Mixed Reality Meetings allow highly flexible communication scenarios combining visualizations with local and remote communication

Mixed Reality Meeting

Description & Example

In a local meeting, participants can don an AR/MR headset and discuss digital models · Remote participants could also join the discussion in form of avatars

Note. Illustration of potential HoloLens application. Meeting participants don headsets and discuss a digital model. The illustration exemplifies how Mixed Reality Meetings can facilitate communication. Source. Hulivahana (2017).

Innovation Characteristics & Evaluation

Primary Substitute: Video Chat

Performance/Pay-Off	+ improved communication + improved team productivity
Complexity/Cost	+ reduced travel costs
Compatibility/Fit	+ localized as well as remote communication
Cognitive Absorption	+ 3D visualizations facilitate communication
Facilitating Conditions	- depends on availability of high-end AR headsets

Diffusion Period: 2030-2040 Saturation Level: medium

Impacted Industries (in order of occurrence)

- Manufacturing Industry
- Architectural & Engineering Service Industry

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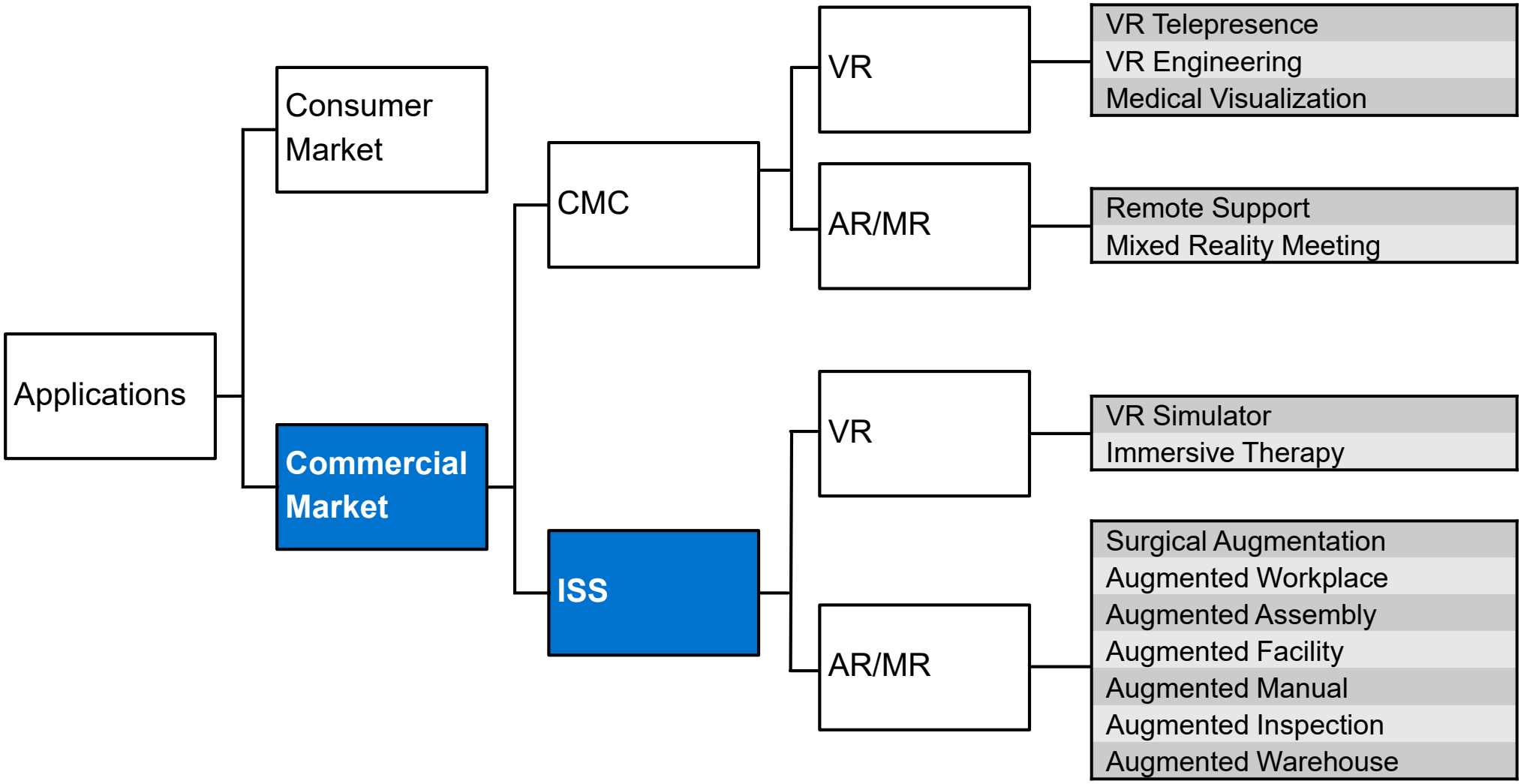
Impact of Virtual, Mixed, and Augmented Reality on Industries

Appendix C (4/4)



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VR Simulators allows optimal acquisition of procedural knowledge through methods of active and situated learning

VR Simulator

Description & Example

Learners can train procedural tasks in virtual environments

Examples for procedural tasks:

- assembly process
- car repair process
- surgical intervention

Note. Surgical intervention conducted in VR supported by haptic simulation. The illustration exemplifies how VR can support learners to acquire procedural knowledge. Source. Wade (2017).

Innovation Characteristics & Evaluation

Primary Substitute: Training in Classroom

Performance/Pay-Off	+ ideal for acquiring procedural knowledge
	+ high learning and retention rates
Complexity/Cost	- expensive content production
Compatibility/Fit	+ standardized training quality
	+ measuring learning progress in real-time
	+ time and location independence
	+ “just-in-time” content adjustment
	- lack of content production skills of trainers
Cognitive Absorption	+ increased student motivation
Facilitating Conditions	

Diffusion Period: 2020-2030 Saturation Level: high

Impacted Industries (in order of occurrence)

- Mining & Quarrying Industry
- Automotive Aftermarket
- Education Industry
- Manufacturing Industry
- Video Game Industry
- Health Care Industry
- Utilities Industry
- Scientific Research Service Industry

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Immersive Therapy allows standardized treatment of multiple psychological or neuropsychological conditions

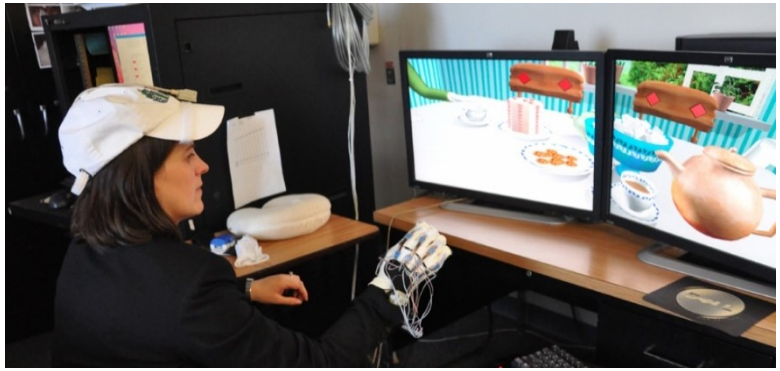
Immersive Therapy

Description & Example

Patients can work on psychological conditions in virtual environments

Examples for treatable conditions:

- phobias (hights, spiders, etc.)
- post-stroke rehabilitation



Note. System for post-stroke rehabilitation. The patient performs actions in VR to relearn motoric skills. Source. Tsoupikova et al. (2013).

Innovation Characteristics & Evaluation

Primary Substitute: Conventional Therapy

Performance/Pay-Off	+ self-treatment and patient empowerment + tested treatment success
Complexity/Cost	+ out-of-the-box therapy
Compatibility/Fit	- social approval of doing therapy in VR
Cognitive Absorption	+ immersive training for patients
Facilitating Conditions	- limited range of medical conditions

Diffusion Period: 2020-2030 Saturation Level: low

Impacted Industries (in order of occurrence)

- Health Care Industry

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Surgical Augmentation allows improved surgical interventions through visualizing the body interior of the patient

Surgical Augmentation

Description & Example

Surgeons receive images of the body's interior in-situ (the location in which they are operating)

Note. In-situ visualization of a patient's x-ray onto foot. The system creates the illusion of looking through the skin. The still exemplifies how surgeons can be supported by surgical augmentation. Source. Navab (2017).

Innovation Characteristics & Evaluation

Primary Substitute: X-ray Image

Performance/Pay-Off	+ increased quality of surgical interventions + higher productivity of surgeons + reduced invasiveness of procedures
Complexity/Cost	+ reduced documentation overhead
Compatibility/Fit	*(not affected)*
Cognitive Absorption	+ surgical interventions will become easier for surgeons
Facilitating Conditions	- medical approval processes

Diffusion Period: 2030-2040 Saturation Level: high

Impacted Industries (in order of occurrence)

- Health Care Industry

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Augmented Workplaces enable a fluent interaction between humans and the Internet of Things (IoT)

Augmented Workplace

Description & Example

Employees can work in a mixed reality work environment in which objects, controls and screens are superimposed on demand

Note. Still from the film Iron Men, in the film Robert Downey junior operates the AI system JARVIS. The system became iconic for the idea Augmented Workplaces. As their implementation depends on high-end AR/MR hardware, implementations are scarce. Source. D'Orazio (2015)

Innovation Characteristics & Evaluation

Primary Substitute: Non-Augmented Workplace

Performance/Pay-Off	+ increased productivity
	+ new work processes
Complexity/Cost	+ miscellaneous potential cost savings
Compatibility/Fit	+ integration of collaboration/telepresence
	+ fluent interaction with IoT
Cognitive Absorption	+ flow experiences of employees
Facilitating Conditions	+ availability of standard applications
	- lack of input devices

Diffusion Period: 2030-2040 Saturation Level: medium

Impacted Industries (in order of occurrence)

- Agriculture, Forestry & Fishing Industry
- Employment Service Industry
- Health Care Industry
- Military and Safety Services

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DOI: 10.14459/2018md1454069

Augmented Assembly increases the employees' productivity in assembly, installation and construction tasks

Augmented Assembly

Description & Example

Employees are guided step-by-step through assembly tasks

Systems reduce the need to look at construction plans, take measurements or check for errors

Note. Still of Accenture's AR system for the assembly of cabin seats in the Airbus 330. The still exemplifies the interactive work process in Augmented Assembly. Source. Accenture (2017).

Innovation Characteristics & Evaluation

Primary Substitute: Construction Plan

Performance/Pay-Off	+ reduced error rate
	+ improved quality
	+ higher worker productivity
Complexity/Cost	+ complexity reduction for workers
	- high upfront configuration
Compatibility/Fit	+ improved accountability
	- cannot handle construction deviations
Cognitive Absorption	+ flow experiences of employees
Facilitating Conditions	+ high availability of 3D data

Diffusion Period: 2030-2040 Saturation Level: high

Impacted Industries (in order of occurrence)

- Manufacturing Industry
- Construction Industry
- Appliance Repair Service Industry

DOI: 10.14459/2018md1454069

Augmented Facilities increase the productivity of shop floor workers in plant maintenance, repair and operation

Augmented Facility

Description & Example

Employees are guided through the production facility and receive task related information

Through integration with the backend system information can be provided efficiently and fed back into the system

Note. Still of UBIK platform created by Augmensys. The still exemplifies how service technicians receive information in complex plant environments. Source. Augmensys (2014).

Innovation Characteristics & Evaluation

Primary Substitute: Conventional Work Process

Performance/Pay-Off	+ increased productivity
	+ new work processes
Complexity/Cost	- high ramp-up costs
	+ reduced documentation overhead
Compatibility/Fit	+ fluent interaction with IoT
Cognitive Absorption	+ gamification of work processes can be motivating for employees
Facilitating Conditions	+ driven by general digitalization endeavors

Diffusion Period: 2020-2030 Saturation Level: medium

Impacted Industries (in order of occurrence)

- Mining & Quarrying Industry
- Manufacturing Industry
- Utilities Industry
- Construction Industry
- Facility Management Industry
- Military and Safety Services

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DOI: 10.14459/2018md1454069

Augmented Manuals guide employees step-by-step through the maintenance and repair process

Augmented Manual

Description & Example

The system recognizes the physical objects and the implemented maintenance and repair process guides the employee through the work process

Integrated checks can ensure that processes were performed correctly

Note. Still of Re'flekt One and Bosch's Common Augmented Reality Platform (CAP). The still exemplifies how information can be provided to car mechanics in a visual and intuitive way. Source. Bosch Auto Parts (2017).

Innovation Characteristics & Evaluation

Primary Substitute: Paper Manual

Performance/Pay-Off	+ reduced error rate + improved quality + higher worker productivity
Complexity/Cost	+ complexity reduction for workers - high upfront configuration
Compatibility/Fit	+ improved accountability
Cognitive Absorption	+ flow experiences of employees
Facilitating Conditions	+ "digital natives" expect to receive information instantaneously

Diffusion Period: 2030-2040 Saturation Level: high

Impacted Industries (in order of occurrence)

- Mining & Quarrying
- Manufacturing Industry
- Utilities Industry
- Automotive Aftermarket
- Facility Management Industry
- Appliance Repair Service Industry

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DOI: 10.14459/2018md1454069

Augmented Inspection allows instant appraisal of deviations through comparing an object to a digital model of the object

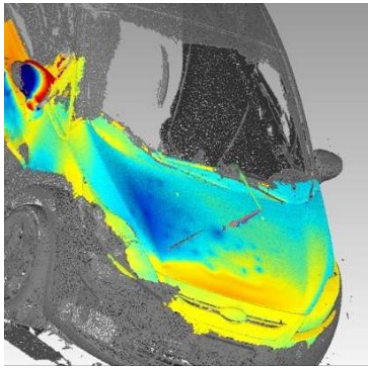
Augmented Inspection

Description & Example

The system compares the physical object with a digital model of the object and shows any deviations to the user

Potential applications are:

- car accident appraisal
- construction progress monitoring



Note. Ngrain uses Voxels to assess collision, hail or scratch damage. The illustration exemplifies how AR can support the appraisal of damages. Source. Smith (2016).

Innovation Characteristics & Evaluation

Primary Substitute: Accident Appraisal

Performance/Pay-Off	+ fast evaluation at initial inspection
Complexity/Cost	+ reduced cost of initial inspection
Compatibility/Fit	- cannot handle strong deviations - potentially not fully accurate
Cognitive Absorption	*(not affected)*
Facilitating Conditions	+ might serve as a good marketing as an app for end consumers

Diffusion Period: 2020-2030 Saturation Level: low

Impacted Industries (in order of occurrence)

- Construction Industry
- Automotive Aftermarket
- Financial & Insurance Industry

DOI: 10.14459/2018md1454069

Augmented Warehouse Systems guide employees through the picking process in warehouses

Augmented Warehouse

Description & Example

The system is integrated with the backend warehouse management system and guides the employee through the picking process

Note. AR Warehouse Management System help employees localize and register objects in warehouses. The still exemplifies the interactive picking process in augmented warehouse systems. Source. Witt and Kothari (2017).

Innovation Characteristics & Evaluation

Primary Substitute: Conventional Picking Process

Performance/Pay-Off	+ increased productivity
Complexity/Cost	+ reduced search cost
	+ expedited work processes
Compatibility/Fit	+ fluent interaction between humans and the Internet of Things
Cognitive Absorption	+ flow experiences of employees
Facilitating Conditions	- automated warehouse management systems override the need for AR systems

Diffusion Period: 2030-2040 Saturation Level: low

Impacted Industries (in order of occurrence)

- Manufacturing Industry
- Transportation & Storage Industry

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Impact of Virtual, Mixed, and Augmented Reality on Industries

Appendix

DOI: 10.14459/2018md1454069

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