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Timothy Jung
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Augmented Reality and Virtual Reality

Changing Realities in a Dynamic World

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Preface

The fifth International Augmented and Virtual Reality Conference was held in Munich, Germany, for the first time in 2019. Under the theme of ‘Changing Realities in a Dynamic World,’ the conference had more than 100 presentations within the areas of Augmented and Virtual Reality in marketing, business, health, education, design, retail, technology adoption, eSports and much more.

This book is a collection of the latest trends in AR and VR presented at the conference, and we hope that the conference and this book will serve as a valuable source for future research and discussion on important issues such as privacy, technology adoption and application design. In addition, this book aims to inform businesses about the latest developments in the areas of AR and VR.

Munich, Germany

Dr. Timothy Jung
Dr. M. Claudia tom Dieck
Prof. Dr. Philipp A. Rauschnabel

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Brand Experience via Mobile AR App Marketing

Eunyoung (Christine) Sung

Abstract The current study adapts holiday mobile marketing to consumer AR experiences by adding an additional dynamic: shared social experience. It therefore contributes to the literature related to both holiday mobile marketing and AR marketing. The study tested the efficacy of holiday AR technology marketing by enhancing authentic brand experiences and engagement. The study aims to apply the Experience Economy framework to AR marketing with additional constructs in order to understand consumer brand experience processes (mediation effects) by measuring consumer responses.

Keywords Holiday AR app marketing · Experience economy theory · New brand experience

1 Introduction

The advent of smart mobile technologies has brought the virtual and real worlds even closer together than previous technologies did (Rauschnabel, 2018). In the marketing and advertising industries, new Augmented Reality (AR) and Virtual Reality (VR) technologies, coupled with Artificial Intelligence (AI) (Hackl & Wolfe, 2017), are among the biggest disrupters. Smartphones and tablets have made AR ubiquitous (Hackl & Wolfe, 2017). It superimposes digital content into users' real environments to augment users' experiences of their surrounding environments (Georgiou & Kyza, 2017). As Hackl and Wolfe (2017) described, "AR overlays graphics or video on top of what people see in the real world using computer vision and object recognition" (p. 9). Users of Android and Apple phones and tablets can download AR apps, making these consumers accessible via AR marketing campaigns.

Experience economy theory (Pine & Gilmore, 1999) has been used to measure consumer experience in using AR (tom Dieck, Jung, & Rauschnabel, 2018), with the importance of creating memorable experiences (Kang & Gretzel, 2012, etc.).

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This theory categorizes people's objectives in seeking experiences according to four motives: entertainment, education, aesthetics, and escapism.

In the current study, we adapt holiday mobile app marketing to consumers AR experiences by an additional experience, *shared social experience*, as our contribution to the AR economy experience literature. Especially during the holidays, company competition for consumer attention is fierce, and firms can better compete when using creative mobile technology marketing (Brendan, 2013). Thus, AR app marketing via mobile could be a great tool of authentic interactive holiday marketing used to create shared social experiences that will get consumer engagement in the holiday season.

The current study contributes to the literature by combining holiday mobile marketing with AR app marketing. We apply the Experience Economy framework to AR app marketing with a new additional *shared social experience* in order to understand consumer brand experience processes (mediation effects) by measuring consumer responses.

2 Theory

2.1 AR Technology Marketing and Consumer Engagement

Marketers persistently try to improve engagement between consumers and brands. Engaged consumers make more transactions per purchase, make more frequent purchases, and become more passionate for the brand (Rosetta Consulting, 2014). Moreover, consumer engagement strategy moves beyond monetary transactions and develops long-term relationships with consumers (Venkatesan, 2017) to make firms achieve a sustainable competitive advantage (Kumar & Pansari, 2016).

One emerging method of consumer engagement involves technology. In a previous study, technology was a good method to increase engagement among users (tom Dieck et al., 2018). The importance of visual marketing in business such as videos, visible cues, and visible impact using technology such as AR (tom Dieck et al., 2018) has been emphasized in research. To examine AR influences on consumer engagement, experience economy theory has been highlighted in previous tourism research (Pine & Gilmore, 1999; tom Dieck et al., 2018); thus, the theory has been applied to our AR holiday mobile advertising.

2.2 Experience Economy Theory

Based on experience economy theory, people seek experiences due to the four motives of entertainment, education, aesthetics, and escapism (Pine & Gilmore, 1999). By applying this theoretical framework to the current study, these experiences with AR would drive consumer engagement with an AR-promoted brand or product. First, in the education motive visitors in a previous study participated in tourism activities to have their knowledge and skills increase (Oh, Fiore, & Jeoung, 2007); this is an effective learning tool to remember as confirmed by other studies as well (Moorhouse, tom Dieck, Jung, 2018; tom Dieck, Jung, & Han, 2016). In applying to our study, an education experience via AR is one in which consumers are able to learn about a holiday-promoted product. Second, enjoyable experiences, or entertainment, are a passive form to promote content; one study that found participants use apps for enjoyable experiences (Jung, tom Dieck, Lee, & Chung, 2016). Third, escapism explains that participants momentarily forget the moment in the real world and immerses in the authentic experiences (Song, Lee, Park, Hwang, & Reisinger, 2015). Fourth, esthetics refer to a user's full immersion (Pine & Gilmore, 1999). In the context of the AR experience among visitors, researchers found that three of the four realms of experience economy framework, except esthetic experience, influenced overall tour experiences (Jung et al., 2016). In the current study, we hypothesize about all four realms of experience economy in the context of holiday AR marketing as follows:

H1: Entertainment experience is positively related to holiday AR ad satisfaction.
H2: Education experience is positively related to holiday AR ad satisfaction.
H3: Esthetics experience is positively related to holiday AR ad satisfaction.
H4: Escapism experience is positively related to holiday AR ad satisfaction.
H5: Satisfaction has a positive impact on new brand experience.
H6: Satisfaction has a positive impact on purchase intention.
H7: Satisfaction has a positive impact on shared social experience intention.

3 Methods

3.1 Study Design and Procedure

A consumable product category (beer brand "Heineken") was chosen for this study. The experiment was conducted with 62 participants who were business majors at a U.S. university.

A scenario-based online experimental study was conducted in the lab with participants' own mobile phones. A testable AR app (in beta) that we made was available in the Google Play store for Android phone users and the App Store for iPhone users. Each participant brought their current mobile phone. The instructor explained what AR is and provided step-by-step instructions to download and install the mobile app with a clickable link.

Once the AR app was installed and functional, participants pointed the AR app in their phones at the Heineken brand logo on a bottle of Heineken. Digital content from the AR app began to appear in their view of their real environment.

3.2 Data Analysis

PLS-SEM was used to test hypotheses in our suggested SEM model. PLS-SEM was used due to the complexity of the structural model to avoid inadmissible solutions, so this method gives adequate statistical power with an admissible solution (Hair, Hult, Ringle, Sarstedt, & Thiele, 2017) of the current experimental study. Our sample size in PLS-SEM was acceptable based on the following guideline: "10 times the largest number of structural paths [should be] directed at a particular construct in the structural model" (Hair et al., 2017, p. 24).

3.3 Measurements

Questionnaires were modified based on the following sources: three items of entertainment (Manthiou, Lee, Tang, & Chiang, 2014), three items of esthetics (Loureiro, 2014), four items of education (Loureiro, 2014), four items of escapism (Loureiro, 2014), three items of satisfaction (Mehmetoglu & Engen, 2011), and two items of purchase intention (Yoo & Donthu, 2001).

3.4 Measurement Model Tests

To test the measurement model, SmartPLS was used. To provide the measurement adequacy, the convergent and discriminant validities, composite reliability (CR), and average variance extract (AVE) were provided. The convergent and discriminant validities of the constructs were acceptable.

For construct validity, all factor loadings were above 0.50 which is the cut-off line (Bagozzi & Yi, 1988) and CRs are above 0.90. Each indicator fell into each expected latent construct and factor-loadings are between 0.79 and 0.95 ($p < 0.05$) (Anderson & Gerbing, 1988). For discriminant validity, the AVE are between 0.769 and 0.906 indicating that all constructs were greater than squared correlations between constructs (Fornell & Larcker, 1981). In addition, there was no concern for common method variance.

4 Results

The overall model fit indices of SEM were based on the results of bootstrapping in a sample of up to 1000 cases in PLS-SEM.

In testing Hypotheses 1 through 4 based on experience economy theory, H1 entertainment ($\beta = 0.728$, $t = 5.327$, $p < 0.001$) and H2 education ($\beta = 0.262$, $t = 2.91$,

$p < 0.01$) on satisfaction were supported ($p < 0.05$). In line with previous findings (e.g., significant paths of entertainment, education, and escapism on outputs, as found in Jung et al., 2016), the current study also found that two (i.e., education and entertainment) of the four realms of experience economy influenced consumer satisfaction on AR holiday promotion experiences. Entertainment was the strongest influence, as previously found (Jung et al., 2016). Thus, consumers responded this holiday AR marketing as entertaining and educational.

Hypotheses 5 through 7 were supported indicating that AR ad satisfaction influenced new brand experience ($\beta = 0.738$, $t = 11.475$, $p < 0.001$), purchase intention ($\beta = 0.513$, $t = 2.948$, $p < 0.01$), and shared social experience ($\beta = 0.475$, $t = 4.516$, $p < 0.001$).

5 Conclusions

First, based on the results, new brand experience through shared AR ad experience leads to purchase intention. In terms of managerial implications, positive new brand experience only matters when consumers are able to enjoy their authentic experiences with others in their social groups. Thus, marketers should make AR ad content for products that consumers can consume in social settings. The selected product stimuli (beverage/food) for holiday promotion was an especially good product category for AR holiday advertising to make new brand experiences since holidays are a time where consumers enjoy food/beverage together with friends and families.

These results, namely that new brand experience by shared AR experience in social setting leads to purchase intention, is our contribution to the AR literature as it works well with consumable holiday-promoted products for the purpose of sharing (e.g., authentic experience, consumable products, holiday). In addition, consumers are willing to generate their authentic experiences in their social groups, helping brand WOM. Those shared feelings or experiences motivate consumers to buy the AR-promoted branded product while enjoying these new brand experiences with others.

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Inside Advertising: The Role of Presence in the Processing of Branded VR Content

Zeph M. C. van Berlo, Eva A. van Reijmersdal, Edith G. Smit and L. Nynke van der Laan

Abstract Virtual reality (VR) has become a new playground for brands and advertisers. However, empirical evidence for the effectiveness of VR branded content is still scarce. The aim of this study is therefore to examine the effectiveness of branded content in virtual space and the role of presence in the processing of brand information when playing a branded VR game. An experiment ($N = 81$) was conducted (using HTC Vive hardware) and showed that playing branded VR games can improve (implicit) brand memory. Moreover, the study showed that the increase in immersion experienced from playing a branded VR game strengthens players' brand memory.

Keywords Brand memory · Virtual reality (VR) · Presence · Immersion

1 Introduction

In the early summer of 2016, influential technology entrepreneur and philanthropist Elon Musk sparked controversy by stating that 'the odds that we are in base reality is one in billions' (Solon, 2016). Where he eluded at the idea that we might already live in a simulated reality (much like the plot of the 1999 blockbuster The Matrix), Musk predicted that, with the current rate of technological development, virtual reality (VR) will one day be indistinguishable from reality.

While VR is currently still far from being indistinguishable from the real world, head-mounted display (HMD) VR technology, also often referred to as *immersive VR* (Seibert & Shafer, 2018), does aim to mimic reality. By utilising various perceptual illusions in a simulated virtual world, this technology creates an experience that feels real for a person wearing an HMD headset.

An example of such an illusion would be the use of stereoscopic imaging to create the illusion of depth. By projecting a slightly different image into each of the player's

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eyes, HMD VR technology utilizes the way human brains tend to process visual information: both eyes send slightly different visual information to the brain, where this information is then fused into one coherent image—an image that includes depth. This slight difference, which is called binocular disparity, can easily be experienced without any VR gear: hold up your finger and focus on it with one eye closed, then switch and close your other eye instead while keeping the same focus. Seemingly your finger moved slightly when switching between eyes, where in reality your finger remained in the same position. Exactly this disparity in visual information from the two eyes enables the brain to detect depth and is utilised by HMD VR technology to create the 'illusion of depth' in virtual reality.

Of course this is just a single example, though by utilising several of such illusions HMD VR technology enables users to engage with a virtual space that 'feels' real. The technology creates, what Lombard and Ditton (1997) defined as, a 'perceptual illusion of nonmeditation', which means that user's phenomenal awareness of both the technology and the external real-world are diminished by the medium (Riva et al., 2007). In the academic literature, this idiosyncratic sensation of 'being there' in the virtual environment (instead of in the real-world) is often called *presence* (Sanchez-Vives & Slater, 2005).

Presence is believed to enhance the vividness and intensity of people's experience in VR (Gabana, Tokarchuk, Hannon, & Gunes, 2017) and is something that can be valuable for advertisers and brands due to its potentially persuasive attributes. Correlational evidence for this was found in a recent study by Tussyadiah, Wang, Jung, and tom Dieck (2018), who showed that presence is positively related to increased attitudes and behavioural intentions in the context of VR tourism marketing. Moreover, research has shown that in specific cases presence can enhance memory performance of information presented in VR (Lin, Duh, Parker, Abi-Rached, & Furness, 2002), which can also be valuable for advertisers looking to drive brand awareness.

Only recently, researchers (e.g., Chen & Wang, 2019; Martínez-Navarro, Bigné, Guixeres, Alcañiz, & Torrecilla, 2019; Roettl & Terlutter, 2018; Wang & Chen, 2019) have started to explore the potential opportunities for brands to utilise HMD VR for commercial purposes. Most of these studies have however focused on in-game VR advertising and other multi-brand applications of VR advertising, leaving much still unknown about the effectiveness of branded VR content from a single brand. Moreover, the potential mediating role of presence in such persuasive contexts has remained largely unexamined. This study therefore aims to contribute to the understanding of the role of presence by examining how it affects the processing of brand information when playing branded VR games from a single brand—also known as VR advergames.

2 Theoretical Framework

2.1 Branded Virtual Reality Games

Branded VR games are defined as covert advertising messages designed to look like regular VR games. They are to VR games what advertorials are to editorial content, meaning that despite their aesthetic similarities, they conceptually differ from regular VR games in the sense that they have a persuasive intent and regular VR games do not (Evans & Park, 2015). In other words, regular VR games are designed to entertain, where branded VR games are designed to persuade—with entertainment being their means rather than their end.

The effectiveness of this type of advertising is often attributed to its interactive nature (Terlutter & Capella, 2013). By utilising game mechanics and game design, gamified advertising is believed to drive consumers' engagement with the branded content and ultimately facilitate the persuasive process—driving various brand responses like brand recognition (e.g., Van Berlo, Van Reijmersdal, & Rozendaal, 2017) and brand attitude (e.g., Wise, Bolls, Kim, Venkataraman, & Meyer, 2008).

Moreover, in gamified branded content brand indicators (like logos) often serve as a functional part of the game, rather than simply being displayed in the background (Terlutter & Capella, 2013). This means that when playing branded VR games, interacting with a brand is often essential to the task that is being performed by the player—for example winning the game. This functional interaction with the brand is expected to improve the encoding of this information, which would then facilitate the retrieval of this information from memory in the future. The following hypothesis is therefore proposed:

H1. Playing branded VR games positively influences brand memory.

2.2 The Role of Presence in a Persuasive Context

When studying VR effects, one of the most important psychological mechanisms to consider is presence. An often used definition is given by Witmer, Jerome, and Singer (2005), who describe presence as 'a psychological state of "being there" mediated by an environment that engages our senses, captures our attention, and fosters our active involvement' (p. 298). Furthermore, they suggest that presence can be conceptualised using four interconnected factors: involvement, sensory fidelity, immersion, and interface quality.

Where this four-factor conceptualisation of presence can be criticised, for example because the factors sensory fidelity (i.e. coherence of sensory stimuli) and interface quality (i.e. performance of the technology) conceptually seem predictors rather than indicators of presence, it does offer a complete operationalisation of a person's experience when playing a branded VR game—and seems therefore suitable when examining the role of presence in this context. The other two factors, involvement and immersion, are psychological states that are, according to Witmer et al. (2005), necessary conditions for presence; involvement as a state in which all attention is focused on (elements of) the VR experience and immersion as the feeling of being completely submersed in the virtual environment.

The likelihood of a person experiencing presence is affected by the richness of a medium and by the user's perception of control while engaging with this rich media content (Klein, 2003). For players of HMD VR games, this means that the multi-sensory stimulation and overall interactive experience many HMD VR games offer, increase the likelihood of players experiencing presence (Seibert & Shafer, 2018). In addition to these two factors, Riva et al. (2007) identified that people's emotions also influence the intensity of this experience in a reinforcing relationship; meaning that experiencing higher levels of arousal strengthens a person's feeling of presence when playing a HMD VR game—and vice versa.

This positive relationship between arousal and presence was recently corroborated in an e-commerce context (Martínez-Navarro et al., 2019) and is important to consider when examining the effectiveness of branded VR games. In particular, because the brand indicators (e.g., logos) embedded in these games are believed to elicit emotional responses from players. Maxian, Bradley, Wise, and Toulouse (2013), showed that exposure for as little as six seconds to logos from well-liked brands elicit arousal. Branded VR games are thus expected to elicit stronger emotional responses than otherwise identical non-branded VR games. Considering the symmetrical relationship between arousal and presence, this would mean that playing branded VR games, compared to non-branded VR games, would elicit overall higher levels of arousal and stronger feelings of presence. In sum, branded VR games from well-liked brands are thus believed to induce stronger feelings of presence than non-branded (yet otherwise identical) VR games.

This increase in presence is believed to improve memory performance and the processing and encoding of information presented in VR (Lin et al., 2002). In a commercial context, this would suggest that people who experience stronger feelings of presence, from interacting with well-liked brand information in a branded VR game, will subsequently be better able to remember this brand information. In sum, presence is thus believed to mediate the effect of playing branded VR games and enhance the successful encoding and consolidation of brand memory—ultimately resulting in better overall brand memory. The following hypothesis is proposed:

H2. The effect of playing branded VR games on brand memory is mediated by presence.

3 Method

3.1 Participants and Procedure

To test the hypotheses an experiment was conducted with a single factor (branded VR game vs. non-branded VR game) between-subjects design. The sample consisted of 81 young adults (72.8% female) with an average age of 22.04 years old (SD = 2.74). The participants were randomly assigned to play one of two versions of a VR game on an HTC Vive with two hand-held controllers. The HTC Vive is HMD VR hardware, which enables its users to look around a virtual space (360°) and to interact with virtual objects within the VR experience. Moreover, participants were able to physically move around inside the virtual environment, within a maximum play area of about twelve square meters. After completing the game, the participants were asked to participate in a five-minute long bogus taste-test and then fill out a questionnaire containing the items measuring brand memory and presence, demographic information, and the manipulation check.

3.2 Stimulus Material

The data that were used in this study were collected during a larger VR project (N = 202). For that project three versions of a VR game were developed of which two were used in this study. The first was a branded VR game ($n = 40$) with an embedded prominently placed logo of the popular chocolate brand Milka. The second served as a control game ($n = 41$) and did not contain any branded content. Except for the brand information, both versions of the game were identical.

Players started the game in a virtual living room with a dining table in front of them. To win the game, they had to solve three rounds of puzzles by using differently sized and shaped puzzle pieces that resembled chunks of a (virtual) chocolate bar. Each puzzle consisted of seven pieces, which were arranged on the dining table at the start of each round. By using the hand-held controllers, players could pick up the pieces and place them inside an outline of the puzzle they were completing. In the branded version of the game the outlines contained the chocolate brand's logo. When a puzzle piece was placed correctly it would remain in the outline; an incorrectly placed piece would fall back onto the table. Most players completed the game within five minutes.

3.3 *Measures*

3.3.1 Brand Memory

To measure brand memory, a word fragment completion task was used (Rajaram, Srinivas, & Travers, 2001). Twenty minutes after playing one of the two VR games, the participants were asked to complete a set of six incomplete brand names (for example 'R _ _ T E _ _P _ _ T' for 'Ritter Sport') for which the third name was always that of the target brand. Each brand name was shown for one second, after which an answer box appeared for the participants to type their answer. Correct completions were coded '1' and incorrect completions with '0' by one of the researchers. About half of the participants (50.6%) correctly completed the name of the target brand.

In line with the research design of this study, an implicit measure for brand memory was chosen to evaluate brand memory rather than an explicit one (like brand recall). This way the effect in the experimental group, that interacted with the brand while playing the branded VR game, could be compared with a baseline—the control group, that did not interact with the brand but did play a similar VR game.

3.3.2 Presence

A 32-item four-factor presence scale by Witmer et al. (2005) was used to measure presence. The reliability of the factors was checked and three of the four factors proved reliable: involvement ($M = 5.28$, $SD = 0.65$, Cronbach's alpha = 0.79), sensory fidelity ($M = 4.68$, $SD = 1.11$, Cronbach's alpha = 0.64), and immersion ($M = 5.83$, $SD = 0.70$, Cronbach's alpha = 0.77). Correlations between these factors ranged from 0.32 to 0.62 and are comparable to those in the original paper—indicating a moderate to strong association between the factors. No index variable was created for interface quality (Cronbach's alpha = 0.49) due to the poor reliability of the proposed factor.

3.3.3 Perceived Brand Exposure

Serving as manipulation check, participants were then asked to indicate whether they believed to have been exposed to a brand while playing the VR game. They could answer this question with *yes*, *no*, or *not sure*. *Yes* was coded as '1' and both *no* and *not sure* were coded as '0' by one of the researchers.

4 Results

4.1 Manipulation and Randomisation Checks

To verify that the manipulation was successful, perceived brand exposure was compared between the experimental and control conditions (10.0%). The results ($\chi^2 = 52.16, p < 0.001$) indicated that in the branded VR condition, significantly more people perceived to have been exposed to a brand (90.0%) compared to the non-branded VR condition (10.0%); meaning that the manipulation was successful.

Moreover, to check whether the sample data were distributed equally across the two conditions, a randomisation check was performed with the demographic variables age and sex. No differences were found for age, t (79) = −1.12, $p = 0.312$) and biological sex ($\chi^2 = 0.00, p = 0.946$) between the two conditions—suggesting that the participants were successfully randomly assigned.

4.2 Main Analyses

To test both hypotheses, a multiple mediation model (Preacher & Hayes, 2008) was estimated using PROCESS (Hayes, 2013; Model 4) that predicted brand memory. A condition variable was used as independent variable and the three factors of presence were included in parallel as mediators. The model was specified following suggestions by Long and Ervin (2000), with 95% percentile confidence intervals (10.000 bootstrap samples) and heteroscedasticity-consistent standard errors and covariance matrix estimators (HC3). An overview of the results can be found in Table 1.

Table 1 Direct and indirect effects mediation model brand memory

		Brand memory				
		b	*SE*	*z*	*p*	95% CI
Direct effects						
Branded VR game		**0.98**	0.48	2.04	0.041	0.04, 1.92
Presence	Involvement	−0.28	0.53	−0.54	0.590	−1.31, 0.75
	Sensory fidelity	0.02	0.25	0.08	0.937	−0.47, 0.51
	Immersion	**0.95**	0.48	1.98	0.048	0.01, 1.89
Indirect effects						
Presence	Involvement	−0.04	0.12	–	–	−0.28, 0.23
	Sensory fidelity	0.00	0.09	–	–	−0.19, 0.19
	Immersion	**0.32**	0.25	–	–	0.00, 0.95

Note To account for the dichotomous nature of brand memory, z-distributions were used rather than t-distributions. Regression coefficients in bold are significant

In line with the predictions, participants who played the branded VR game (65.0%) performed better in the word completion task than those in the VR control game condition (36.6%, $p = 0.041$). This implies that playing a branded VR game improves players' brand memory and results in better retrieval of the brand name. Additionally, as shown in Table 1, only the presence factor immersion positively mediated the effect of playing the branded VR game on brand memory. Non-significant results were found for involvement and sensory fidelity. In sum, this means that the data support Hypothesis 1 and partially support Hypothesis 2.

5 Discussion

An experiment was conducted to examine the workings of branded VR games in HMD VR and the role of presence in the processing of the embedded brand information. The results indicate that playing a branded VR game is positively associated with future retrieval of the brand's name from memory and that immersion experienced from playing a branded VR game strengthens the encoding of this information. Overall, this indicates that branded VR games can be used effectively to communicate brand information.

5.1 Presence in a Persuasive Context

When determining the role of presence in a persuasive VR context, the results seem to indicate that only immersion facilitates the processing of brand memory. In other words, immersion experienced from playing a branded VR game seems to drive brand memory.

Even though all four factors of presence were expected to affect brand memory, the current findings could be explained by considering insights from the cognitive capacity model (Lang, 2000). In short, the central theorem of this model suggests that a person's cognitive capacity is limited and that cognitive processes require (and compete for) this finite capacity—similarly to the random-access memory of a computer, its maximum capacity limits the amount of tasks that can (successfully) be performed simultaneously at any single point in time.

Playing a VR game requires players to perform several complex and often cognitively demanding tasks; from interacting with the virtual objects to simply making spatial sense of the simulated virtual space. In other words, when playing a VR game, one's cognitive capacity available for additional cognitive tasks (like successfully processing brand information) is generally believed to be limited. This was demonstrated in a recent study comparing the effectiveness of in-game advertising across various platforms (Roettl & Terlutter, 2018), which reported adverse effects of exposure to brand placements in VR, when compared to desktop and stereoscopic 3D, on overall brand memory.

In line with the cognitive capacity model, a higher accuracy in brand memory could suggest that a player had more cognitive capacity available to process the brand information during the game. From this perspective, the results of the current study could suggest that the increase in immersion from playing a branded VR game is related to the availability of cognitive capacity among player. Future research would be required however to determine whether immersion diminishes the cognitive capacity available to process the VR environment, because the current study design did not allow to test for the causal relationship between presence and cognitive capacity.

Furthermore, the results suggest that involvement and sensory fidelity do not affect brand memory directly. Important to consider however, is that Witmer's conceptualisation of presence (Witmer et al., 2005) and the correlations between the factors of presence, do indicate that sensory fidelity and involvement are related to the players' levels of immersion. This would imply that both involvement and sensory fidelity might influence brand memory indirectly via their relationship to peoples' levels of immersion. Although the current research design does not offer concluding evidence for this relationship, it seems advisable not to ignore the factors involvement and sensory fidelity in future research.

5.2 Limitations and Suggestions for Future Research

While this study offers novel insight into the workings of presence in a persuasive context, it does come with some limitations. Foremost, the scale that was used to measure presence did not prove to deliver four reliable factors, as was suggested by the original authors (Witmer et al., 2005). In addition to the only borderline reliable measure for sensory fidelity, failing to construct a reliable measure for interface quality might have affected the explanatory powers of the effects of presence. It is possible that interface quality mediated (part of) the effect of branded VR games on brand memory, although since this factor could not be considered in the model this conclusion cannot be drawn with the current data. Besides, it is also possible that, considering that the scale was developed and validated with less modern VR hardware, the items measuring interface quality do not entirely align anymore when measuring presence in an HMD VR context.

Considering that VR technology—and thus the quality of the virtual interface—has improved considerably since Witmer et al. (2005) published their paper, it is not unlikely that the importance of interface quality as a factor for measuring presence has slightly decreased over time. Future research into the effects of presence in a HMD VR context could therefore consider utilising different operationalisations of presence. A recent study by Tussyadiah et al. (2018) offered an extensive overview of various measures for presence and suggests to use the conceptualisation by Wirth et al. (2007) when studying HMD VR. This conceptualisation focuses on the dimensions (1) self-location and (2) possible actions to measure presence. Alternatively a shorter and more recent version of their original scale can be used (Hartmann et al., 2016).

5.3 Implications for Theory and Practice

The results of this study demonstrate that branded VR games from well-liked brands can positively affect brand memory. Immersion was identified as a possible underlying mechanism for the effectiveness of this type of VR advertising, which could be explained by considering the limited capacity model (Lang, 2000). Note that when compared to previous research into VR advertising, the results seem to suggests that people process VR advertising messages from single brands (e.g., VR advergames) differently from VR advertising messages that include multiple brand placements (e.g., in-game VR advertising). For both theory and practice it seems therefore important to consider the amount of brand information that is included in the VR advertising message, for this could potentially influence its effectiveness.

For practitioners, the results show that branded VR games can be an effective tool to promote brand memory. Moreover, it seems that the effectiveness of branded VR games can be improved by fostering a more immersive VR experience. The data indicate that players who were more immersed into the branded VR game were better able to retrieve the brand's name from memory afterwards, implying that immersion facilitated the processing of the brand information while playing. The coherence of sensory stimuli while playing and players' involvement with the virtual experience did not seem to directly influence brand memory.

5.4 Concluding Remarks

Considering Musk's prediction that virtual reality will one day become indistinguishable from our reality (Solon, 2016), VR technology and application are likely here to stay. This suggests that for the years to come, investing in and understanding VR will become more important for both the academy and practice. While today, a perfect union of the virtual and the real still seems far away, the current empirical evidence seems to suggest that the power of modern HMD VR does not necessarily relates to its ability to *look* like reality, but rather to its ability to *feel* like reality.

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How to Engage Fashion Retail with Virtual Reality: A Consumer Perspective

Liangchao Xue, Christopher J. Parker and Cathryn A. Hart

Abstract Highly valued consumer experiences occur when designers understand how emerging technology—such as Virtual Reality—is presented in an emotionally engaging format. For fashion retailers to ensure longevity through new retail models, designers must understand how Virtual Reality can offer an exceptional retail experience. Our research addresses this question by interviewing 22 young professionals on attitudes towards Virtual Reality, motivation to shop through v-Commerce, and the moderating variables that influence virtual environment perceptions. Our results prove consumers expect a vivid shopping environment, with authentic product features instead of than more common simulated environment. We prove hedonically motivated consumers are more open to v-Commerce than utilitarian consumers, and Consumers aged 18–34 regard interactivity, personalisation, and social networking as critical to offering that a cost-efficiency shopping experience. This paper thus establishes the fundamental design rules for v-Commerce platforms, allowing designers to create effective retail environments, sympathetic to the consumer's cognitive desires.

Keywords Virtual reality · V-Commerce · Retail · Shopping experience · Consumer

1 Introduction

To secure the future of the UK retail sector, retailers must understand how to present emerging technology in a format that facilitates consumer purchase behaviour, based on established consumer investigation methods (Parker & Wang, 2016). Despite being worth over £60,800 million (Dover, 2018), the UK fashion retail sector faces an uncertain future. Highstreet footfall is at a crisis level, electronic commerce's (e-Commerce) performance is weakening and retailers are increasingly reliant on debt (Santi, 2019). According to KPMG (2018), overall sales were down by 3.1% in April

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2018, the biggest decline since 1995. In 2018, online retail sales also experienced the lowest November growth since 2011, increasing by only 8.1% year-over-year (IMRG, 2018). Developing disruptive technologies such as Virtual Reality (VR) as a retail platform (v-Commerce) offers great potential to increase the competitive advantage of any retailer who can tap into the shopping behaviours of consumers. Despite such a perspective being heralded for over a decade (Arakji & Lang, 2008; The VR/AR Association, 2017) v-Commerce has yet to make a significant impact on the shopping behaviours of consumers. V-Commerce's lack of disruption is because of industry holding no consensus on the optimal consumer experience or how to design virtual stores for high return on investment (Xue, Parker, & McCormick, 2018). Without understanding the format consumers desire from v-Commerce interactions, virtual retail will remain an interesting marketing gimmick instead of a pivotal driver of sales (Bonetti, Warnaby, & Quinn, 2018).

This paper aims to investigate the format of v-Commerce experience fashion consumers best respond to (e.g. fully immersive/augmented). To address this research aim, this paper embodies three research objectives:

1. *To understand the consumer response (attitudes and motivations) to v-Commerce*, allowing retailers to meet the growing and diversified needs of consumers and enhance competitiveness.
2. *To understand the moderating variables that affect shoppers' perception when developing a virtual environment for retailing*, allowing designers to develop more effective and emotional seductive v-Commerce platforms.

2 Methodology

2.1 Setting and Sample

Consumers aged 18–34 are the most open to VR acceptance, with gender showing no difference between gender, demonstrating a broadening of traditional segregating categories (Nielsen, 2016); recognising digital natives' emergence into mainstream consumers. To generalise the data, we collected responses with both males and females, in full-time employment, and aged 18–45. We also included VR developers to obtain an industry-centred perspective. 22 participants were recruited through purposive sampling, ensuring a suitable spread of participants across the sampling frame; including 20 consumers and two VR developers. We chose qualitative methods to achieve deeper emotional insight than widespread surveys provide. Our semi-structured interviews were conducted Between August and October 2018 within UK urban areas: London, Manchester, and Sheffield; preferring universities, coffee shops, and shopping centres. These locations facilitate collecting data from college students, income earners and shopping fans.

2.2 Data Collection

Preceding data collection, the researcher showed participants two concept videos of v-Commerce high-street environments; for ASOS (Fig. 1) and Alibaba (Fig. 2). Showing the concept videos was to elicit the participant's response to questions before conducting semi-structured interviews. The first high street environment (ASOS) shows an initial user interface of virtual shopping environment. The second high street environment (Alibaba) shows the shopping process of a customer wearing a VR headset entering a virtual Macy's store to purchase a handbag. By viewing the v-Commerce video prototypes, participants could understand v-Commerce without requiring the experimental equipment Alibaba and ASOS utilised: equipment currently unavailable to the public. Subsequently, the participant's reaction to both forms of v-Commerce, alongside their desires and preferences that influence their v-Commerce perceptions, could then be gauged.

Fig. 1 ASOS: Trillenium demo app (VIDA 3D, 2015)

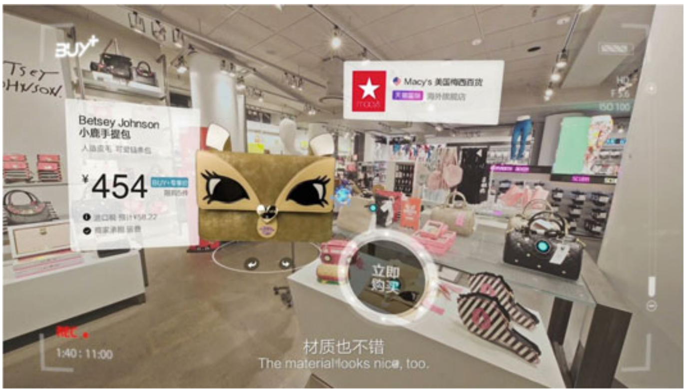


Fig. 2 Alibaba: Buy + VR shopping experience (Alibaba Group, 2016)

To address the research objectives, the interview question sheet targeted consumer attitudes, motivations, shopping behaviours and influential variables.

- Consumer attitudes of v-Commerce were investigated in line with the recommendations of Ha and Stoel (2009) and Kim and Forsythe (2008), investigating consumer e-shopping acceptance in a Technology Acceptance Model through technology acceptance, usefulness, ease of use, enjoyment and trust.
- Motivation towards v-Commerce was investigated in line with the recommendations of Arnold and Reynolds (2003), classifying consumer shopping motivation into either hedonic motivation (gratification shopping, social shopping, idea shopping, role shopping and adventure shopping) and utilitarian motivation (efficiency shopping and achievement shopping).
- To understand the consumers' shopping behaviour, the questionnaire explored the consumer's different behaviour in offline and online shopping channels through perceived value (Escobar-Rodríguez & Bonsón-Fernández, 2017), shopping experience and decision-making (Katawetawaraks & Wang, 2011).
- The influential variables that affect shoppers' perception of v-Commerce were investigated in line with the recommendations of Xue et al. (2018), focusing on comfort, content, functionality, media richness, perceived value, social networking and user experience to reveal moderating variables towards v-Commerce.

Each interview took from 30 to 45 min, with the researcher capturing audio via iPhone and recoding pen.

2.3 Data Analysis

The researcher analysed full transcripts with NVivo 11 (QSR, 2017), with thematic analysis aiding a deeper insight into the data than otherwise possible. Through thematic analysis insights into consumer reactions to VR within v-Commerce were gained alongside their desires/preferences and the factors that influence their perceptions toward v-Commerce.

3 Results and Analysis

3.1 Consumer Response to V-Commerce

The key themes derived from thematic analysis are presented within Tables 1 and 2.

Table 1 Relevance characteristics of VR in interview—coding references (technology acceptance)

Theme	Category	Themes from data	Participants aged 18–34	Participants aged 35–45
Technology Acceptance	Positive	Novelty effects	13	4
		Benefit from VR	19	3
	Negative	Expensive	15	2
		Adaptation	4	5
		Change of shopping behaviour	0	5
		Technology awareness	2	5

Table 2 Relevance characteristics of VR in interview—coding references (influential variables)

Theme	Category	Themes from data	Participants aged 18–34	Participants aged 35–45
Comfort	Positive	Convenience	25	10
		Without crowding	19	0
		Easy access	17	1
Content	Environment	Authenticity (product and environment)	26	8
		Pleasant environment (light and sound)	7	3
		Designed store layout	9	4
	Information	Customer reviews	14	7
		Easy navigation	8	6
	Product feature	Vividness	12	7
Functionality	Accessibility	Simple procedure	11	4
	Interactivity	Product interaction	30	7
		Social interaction	26	4
	Personalisation	Personal service	12	6
		Personalised interface	14	5
		Product recommendation	7	1

3.1.1 Attitude Towards V-Commerce

Results shows the younger generation to be v-Commerce's main adopters. As shown in Table 1, 94% of participants in the age group of 18–34 were familiar with VR. Those same participants showed great potential to experience VR as the technology could offer many benefits for them that match their interest in innovative technology. Conversely, 40% of participants aged 35–45 showed negative attitudes about adopting v-Commerce. This is due to the challenge of altering existing shopping modes and behaviours compared to a younger audience. The results prove hedonic consumers to be more open to accept v-Commerce than utilitarian consumers. As participant 7, from the 35 to 45 age group, stated "*If you really enjoy shopping… you would like VR shopping process. But for me…I just know what I want and go and buy it. [VR] seems a bit would probably slow me down, because what I like about websites is that it will make it quicker.*"

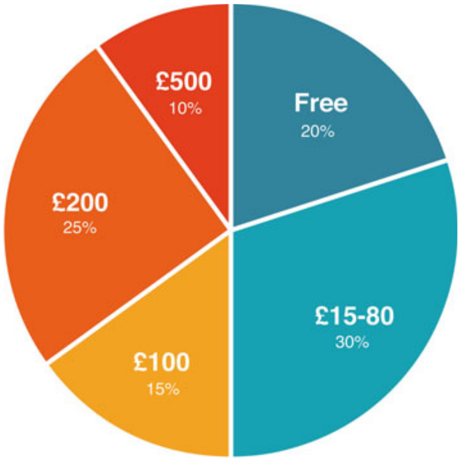
3.1.2 Technology Acceptance Barriers

The results predict v-Commerce shall manipulate and revolutionise consumers' purchasing habits. This is supported by participants from 35 to 45 age group who were concerned how their shopping behaviours in v-Commerce would change through, for example, emulating 3D environment, sensitive and interactive home shopping or a different check-out procedure. As participant 5 referred "*I like to be able to feel things and hold them. And there are a lot of aspects of virtual shopping that I wouldn't feel comfortable unless I could experience and feel the product in person.*" The other acceptance barrier of v-Commerce lies in financial factors, as half of the participants worried about being unable to afford expensive VR goggles for home interaction; costing from £399 (Oculus, 2019). Among them, 70% participants expect the price of a headset should be under £200, while another 20% proposed that retailers need to take the responsibility of the cost of v-Commerce; see Fig. 3.

3.1.3 Motivation Towards V-Commerce

14 participants pointed out they are willing to try VR shopping because of the novelty effect. Amongst the 14 participants, 50% of feel they would try it as part of an experiment, but not for long-term use. As participant 5 stated; "*I guess, just for the fun experience of it, to try it out. But otherwise I'm pretty happy with current in -store and online shopping.*" Hence, if v-Commerce cannot offer additional value, or experience than current shopping channel, consumers' motivation toward v-Commerce would decrease rapidly.

Fig. 3 The percentage of respondents based on the cost they willing to spend on A VR headset



3.2 The Moderating Variables that Affect Shoppers' Perception When Developing Virtual Environment for Retailing

The key themes derived from thematic analysis are presented within Table 2.

3.2.1 Convenience and Accessibility

The result from the interview shows 70% of participants perceived convenience in v-Commerce as a top priority to them, helping consumers to save effort and make decisions. According participant 18 "*convenience should be very important, priority. You are asking users to learn a new skill, so it should be very convenient and provide a great experience for them to keep using it. Otherwise they may just want to feel fresh [novel] for the moment*". Interestingly, no participants considered time saving as an outcome from v-Commerce. This is surprising because consumers will spend more time browsing or interacting with different features when they are shopping in physical stores.

3.2.2 Authenticity (Environment and Product Feature)

Authenticity of v-Commerce environment and products was a key influential variable that affects consumers' perception. 18 participants wished to experience v-Commerce as lifelike interactions, otherwise there could be a negative impact on consumer trust in v-Commerce. For example, presenting authentic environments with the realistic size and colour of the products, rather than stylised interfaces. Participant 4 stated: "*I'm wondering if I will be able to see the real sizing of the item* *or be able to hold up two of the sizes like small and medium; you could see how different they are, which will reduce the risk of online shopping*". Such interactions are, however, outside contemporary VR's capabilities, being restricted to 360° video and preventing interactivity. Consumers, at this point, have too high expectations of v-Commerce, resulting in dissatisfaction with current technology unable to satisfy their desires.

3.2.3 Interactivity

Product interaction, social interaction, and personalised services are the most valued function in v-Commerce; see Table 2. 75% of participants believe interacting with products will improve product perception and provide a better understanding of the products, as long as the technology is mature. As participant 12 said: "*The interactivity should be smooth and active. If it's very clumsy and hard to use, I can easily hate it. But if it's very responsive and easy to use, I will feel very much engaged and my perception may change positively, which may stimulate my willingness to spend money.*"

Virtual sales assistants in VR were perceived as being very helpful and interesting according to 19 participants. As participant 8 referred; "*For Amazon, there is no one [who] can interact with customers (live chat), VR could do this. A real or AI sales assistant both would improve the online shopping experience. Disabled people (deaf), would be helpful to have live chat.*" Additionally, 19 participants regard social dimension as part of their entertainment. Consumers feel positive about shopping together with friends/family in a virtual environment, even if they are not in the same place in reality.

3.2.4 Personalisation

Pairing shopping behaviours could improve consumers' shopping experience and make v-Commerce more attractive. 15% of participants mentioned they prefer to keep privacy sometimes during online shopping; comprising of persons who feel introverted, less sociable, or prefer shopping alone. The participants would, therefore, like more control over the social interactive function. According to participant 10: "*If I use VR, a big part of it may because I want to shop alone sometime. Even though other's opinions will influence me …The only interactivity I require is the product itself and sales assistant.*"

Personalised service was a feature 70% of participants said they were keen to obtain through recommendation of new arrivals or matching items from the customer's preference and personal suggestions, as answered by participant 18: "*I hope to receive personal advice from a sales assistant, the sales assistant will provide further product or alternative information if the consumer has been focused on one product for a long time*". All participants believed that human service is much more reliable than the gruff reply from artificial intelligence (AI) that can only answer a few questions. Consumers may only know about a single product, yet often seek information about similar products within different price categories or from alternative brand. Consumers may, therefore, benefit from the 'guess what you like' function to screen out which product is most suitable for them.

4 Discussion

4.1 Consumer Response (Attitudes and Motivations) of V-Commerce

Because of the changing consumer expectations and technology development, there is scant definition of consumer behaviour in VR environments. Therefore, we need to understand consumer response to the interactive technology in a high street retail setting.

Table 1 shows that younger people responded more positively to v-Commerce than older people. Older participants find it is difficult to embrace such new technology because of the changing shopping habits; confirming the propositions of Nielsen (2016). Even though most consumers are open to trying v-Commerce, the potential allure does not convince them to use it; especially for participants aged from 35 to 45. This is because consumers regard v-Commerce as a new technology producing a significant novelty effect. Once v-Commerce losses its appeal or unique value, there will be less to motivate consumers to use v-Commerce. Eventually, consumers will quit the virtual world. The other reason lies in consumers will not get any added value from the product itself when they spend money on the VR headset/accessories, which leads to reducing the consumers' perceived value of v-Commerce.

This study reaffirms Papadopoulou's (2007) findings, that virtual reality shopping environments might not hold for experienced users, as shopping in such an environment can be deemed as time-consuming or boring, because of their familiarity with existing sites. Given the novelty effect disappears at some point, the overall effectiveness of v-Commerce is believed to be limited in generating positive consumer evaluations. Consumers' shopping behaviour varies depending on whether their search motivation is for fun or efficiency. This study found that if the consumers are going to the store for specific items, they may not be inclined to use v-Commerce, unless they have more time and would like to browse the store.

Since v-Commerce doesn't improve the quality of products and or decrease their price, hence, retailers must consider how to provide extra value on products or services and distinctive experience through VR platforms to reduce consumer perception of price. Besides, to keep v-Commerce attractive, content design becomes important, where v-Commerce experience should the traditional physical stores it may be incorporated into; if employed in a high street setting. This will reduce consumers' time and energy costs in the entire shopping process. To reduce technology acceptance barriers, VR developers should focus on develop human factor theory in VR shop design (i.e. social dimension, eye-tracking, disadvantages shoppers' considerations etc.) to relieve the needs to change original shopping behaviour for older and disadvantages audiences.

4.2 The Moderating Variables that Affect Shoppers' Perception When Developing Virtual Environment for Retailing

V-Commerce environment differs from online shopping environments, and it therefore becomes difficult to explore consumers' desires since most consumers have not experienced virtual shopping. Hence, understanding consumers motivation towards v-Commerce becomes important for developing v-Commerce at the initial stage.

The most significant finding from this study is that convenience has been regarded as the most influential factor for home shoppers. Interestingly, none of our participants believe virtual shopping could help them to save time on achieving a specific shopping task and distrust information provided by virtual shopping within virtual-built environments and products. Therefore, participants expect to improve the credibility of v-Commerce through obtaining vivid interaction with products to enhance their product perception, and helpful virtual assistants to provide more specific/detailed product information and satisfy a variety of personal needs (personal service). As such, the faceless interaction with the usual web interface is advanced to a human-like communication, where the customer talks and has a virtual eye contact with the salesperson. We also found the social dimension as hedonic value is key to v-Commerce. Participants feel excited to interact with their friends, family, or the public in the virtual world. Through virtual communities, customers can post articles, reviews, and product recommendations, with feedback from other customers, facilitating consumer trust.

In 2019, the consumer's low level of trust in v-Commerce is due to the technology's inability to provide personal multisensory in-store product experiences, or match e-Commerce's convenience. e-Commerce is more likely to be goal-focused rather than experiential. Wolfinbarger and Gilly (2001) showed that for goal-oriented users, e-Commerce retailers must prioritise easy to access and use information instead of content and community. The functions such as welcome, recommendations, search, product and product-related information view, short video about the fitting effect, order placement, purchase and order-racking are currently typical of conventional online stores. The same practical functions, when provided within a virtual reality shopping environment, can be preferred by customers and can also build a customer's trust in v-Commerce. On the other hand, Roth, Latoschik, Vogeley, and Bente (2015) found that social behaviour challenge for both technical aspects, such as the real-time capacities of the systems, but also psychological aspects, such as the dynamics of human communication. Our results also show, many participants desire privacy during online shopping, leading some consumers to prefer shopping alone. These outcomes are interesting since social shopping motivations associate with a greater preference for e-Commerce engagement (Parker & Wenyu, 2019). For consumers, personalised interfaces become a critical factor in effective v-Commerce interfaces.

Therefore, the study suggests the overall shopping operation have to be easy access, including hand and head movements, it should conform to the daily behavioural logic, which would ease the need for older audiences to change their current shopping behaviour. Moreover, v-Commerce designers should put emphasis on the social dimension and creating real-world shopping environment and authentic product model. Creating real-world shopping environments will help consumers to improve product perception and enhance the credibility of v-Commerce environment. Because of the consumers' diverse demand, the interface of v-Commerce could offer different options or modes to satisfy both hedonic and utilitarian consumers from personalised entertainment functions (i.e. social interaction, adventure shopping experience, background music, lighting etc.). In addition, intelligent sales assistants will be very important in v-Commerce to provide product information and advise consumers during their shopping; it would evolve by higher accessibility, but companies require an extensive database.

5 Conclusion

To conclude, this study investigates consumer responses and expectations toward v-Commerce in a high street retail setting. The most positive response is hedonic consumers and 18–34 aged consumers, as older audiences resist changing their purchasing habit. Meanwhile, most participants point out novelty effect is their prime motivation to try v-Commerce. As consumers are chiefly motivated by a products' quality and price, factors v-Commerce cannot improve upon, v-Commerce's must find and focus on alternative purchase motivators. We recommend retailers offer promotions along with the products to increase perceived value to consumers, this would motivate utilitarian shoppers to adopt v-Commerce. V-Commerce platforms must increase consumer engagement by including high quality content. High quality content, directed by designers, must be achieved through more creative and challenging interfaces than current practices of recreating physical spaces can offer. For designing such alternate interfaces, the v-Commerce designer must be moderated by shopping convenience and product accessibility (i.e. friendly user interface and easy process etc.), authentic environment and product representation, interactivity (i.e. product interaction and social interaction), and personalisation (personalised interface and personalised service). Ultimately, v-Commerce environments that excel in delivering creative—yet accessible, authentic, and personalised—experiences stand the greatest chance of facilitating consumer purchase behaviour; contributing to the high-street's regeneration.

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Enhancing Product Configuration and Sales Processes with Extended Reality

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Abstract The advent of extended reality (XR) technologies is opening new doors for augmenting customer experience and enhancing sales processes. XR is promising not only for enhancing new product visualizations, and supporting sales processes by fostering discussions, but also for placing an emotional and tangible connect to future product designs. In this paper, state of the art and challenges of XR-based group product configuration for industrial applications are discussed. A solution concept and prototype for virtual and augmented reality is presented, with group configuration features for collaboration. Evaluation concepts and design insights are drawn out.

Keywords Mixed reality · Sales processes · Collaboration · Annotation

1 Introduction

Extended Reality (XR) has been defined as the superset which includes the entire spectrum from "the complete real" to "the complete virtual" in the concept of reality-virtuality continuum introduced by Milgram and Colquhoun (1999). The realm of

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XR is rapidly transitioning from interactive entertainment experiences to commercial applications due to their spatial and visual transformative power. Virtual and augmented reality together is being deployed to enrich design experience, and aiding to visualize consumer expectations (Berg & Vance, 2017). Due to their inherent emotional and cognitive benefits, they are also being as educational and assitive tools (Freina & Ott, 2015). Owing to its human-centric and immersive quality, virtual and augmented reality are befitting technical solutions for enabling co-designing and co-creation interaction experiences. Virtual and augmented reality have to their advantage, the ability to represent non-existent structures accurately, as well as to examine fit and suitability of a product before ordering—hence serving as a vital configuration and pre-sales tool. Although several applications exist which tap into virtual reality for social interactions, or for (individual) design experiences, there is still room for development of products that combine these elements. We conjecture that the state of the art in virtual reality is hence ready to be extended to co-configuration scenarios (i.e. community configuration) where different preferences of users may be expressed, discussed, consensus arrived at, and subsequently combined to and support the computer aided group-selling process. This work presents the key aspects of community configuration as a group co-creation problem, followed by the benefits of mixed reality for addressing it. First prototypical applications to address the problem are presented, followed by an evaluation concept, discussion and industrial applications.

2 State of the Art

2.1 Community Configuration

In the context of configuring complex products and scenarios where a group of users are involved, group-based configuration systems have been recognized as useful tools to draw different users' preferences and arrive at a group concensus (Felfernig, Atas, Tran, & Stettinger, 2016). Leckner and Schlichter (2005) introduced the term community configuration, based on the that customers can ask others about their opinions and experiences, while facing product uncertainties, for delegating product creation tasks, and for extending their knowledge base. A systematic classification for different categories of customer cooperative product configuration which is illustrated in Fig. 1.

The three dimensions of customer cooperation are *synchrony, cognition* and *the extent of customer cooperation* (Leckner & Schlichter, 2005). The *synchrony* criteria can be categorized as synchronous and asynchronous cooperation: the former is achieved, when the configurator can be used at the same time and the customers support each other in real time. If the cooperation is asynchronous, customers support each other using offline and notification methods. The second criteria is the *cognition* of customer cooperation, wherein the cooperation can be a perceived or

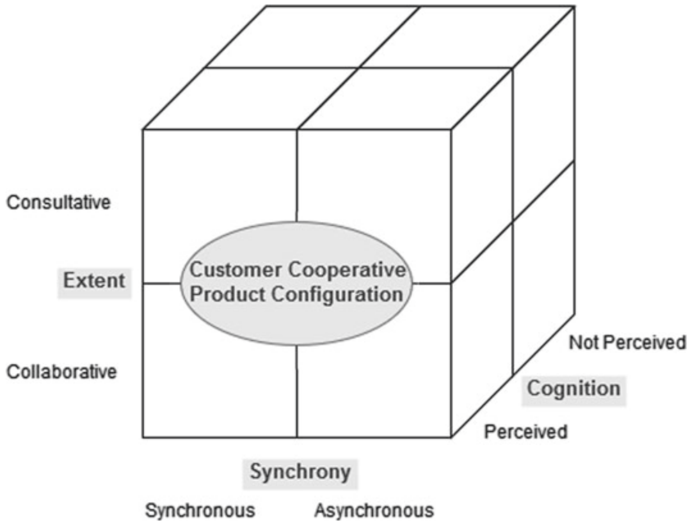

Fig. 1 Dimensions of customer cooperation in community configuration

non-perceived interaction. Perceived cooperation is given, when all participating customers realize that they are supporting each other during the configuration process, whereas this is not realized in non-perceived cooperation. The *extent of customer cooperation* can be distinguished between consultation: where the customers get advice from ratings, experience reports or detailed statements; and collaboration: where the customers work and configure the same product model.

There are some examples and approaches for customer cooperative product configuration in the following works (Stettinger, 2014; Tran, Atas, Stettinger, & Felfernig, 2016; Mendonça, Cowan, Malyk, & Oliveira, 2008; Felfernig et al., 2016; Velásquez-Guevara et al., 2018). These approaches all have in common that they use an asynchronous way of collaborating. Synchronous collaboration has been more researched in the context of real time groupware editors, than product co-creation. A well-known application is that of Google Docs, where users are able to collaborate as well as perceive the presence and contributions of other users in real-time. To the best of our knowledge, there are neither theoretical solutions nor products in practice for the area of collaborational product configuration systems in real time, and hence deems a promising area of new product development and research. Another important subject in community configuration is the visualisation and the product experience of the configurable product. Therefore, VR and AR approaches can be used to ensure an emotional and tangible connection for the customer in the configuration process.

2.2 Virtual Reality for Sales Process and Co-creation

Virtual reality technologies offer the possibility to visualize, analyze and evaluate complex projects using descriptive 3D models. In addition, shared reality applications enable changes to be made directly to the models in virtual environment and collaborative working on projects. In order to work in situ as well as with geographically distant people, collaborative systems are needed. Collaborative systems may be broadly divided into four different groups: synchronous and asynchronous (time-related), and co-located and distributed (location-related) collaboration (Kiyokawa, 2007). In order to ensure direct cooperation, synchronous methods, albeit challenging, are well suited for co-creation in a VR-based application. The location-related aspect does not play a major role in VR for initial collaborative settings, since the users will later work together in a virtual space anyway, however future extensions might necessitate co-located virtual interactions. With distributed collaboration, the only criteria that needs to be considered is that communication between users is made possible over other means, such as Mobile or Web applications.

A summary of existing platforms that facilitate configuration in virtual reality is provided in Fig. 2. Expivi provides a tool for configuration in VR. It allows the user to configure products in 3D and therefore design them according to individual needs (Expivi). Collaborative approaches in VR include Improov3, Innoactive, IrisVR and MeetinVR. Improov3 is a software for teleconferencing in virtual reality. The application integrates CAD objects into the virtual world so they can be viewed and edited by multiple users simultaneously (Improov3). Innoactive also offers possibilities for collaborative treatment of 3D objects in VR, but aims at planning and training real-world processes, such as manufacturing processes at Volkswagen group (Innoactive). IrisVR was developed to discuss 3D objects, mainly architectural and design components, in VR. The application offers numerous tools. These include color processing, navigation, labeling, measuring and a layer system. IrisVR also provides multi-user support and offers communication tools (IrisVR). Likewise developed for discussion

Platform	Direct co-operation	Information about objects	Information about user	Information about other user' activities	Viewing hidden objects	Import and move 3D objects	Configuration	Synchronous configuration	View multiple objects	Verbal communication	Non-verbal communication (gestures)
Expivi (2018)		•				•	•		•		
Improov³ (2019)	•	•			•	•	•	•	•	•	•
Innoactive (2019)	•	•	•			•			•	•	•
IrisVR (2019)	•	•			•	•	•	•	•	•	•
MeetinVR (2019)	•		•			•	•		•	•	•
	Multi user	Information			Navigation	Manipulation			Visualization	Communication	

Fig. 2 Comparison of virtual reality configuration and collaboration platforms

is the multi-user application MeetinVR, which focuses on virtual reality discussions (MeetinVR). In contrast to many other applications, the software provides information about the activities of other users (e.g. personalized profile pictures of the users; which user speaks when, etc.). This is especially important in terms of collaboration and co-creation, and awareness of the presence of other users.

In summary, products that facilitate social interaction in VR are available, however there are only a few products that combine these aspects and thus realize co-creation in VR, and none of these products specifically focus on product configuration for end customers as a generic platform that can be used across several application domains and group buying scenarios. In addition, important aspects of co-creation, such as information about the activities of other users (awareness of others), are either not implemented or only implemented to a limited extent.

2.3 Augmented Reality for Annotation-Based Group Configuration

Augmented reality is most commonly used for placing virtual objects in a real context. It can also be used or to enrich the environment with annotation and digital note-taking mechanisms (Clergeaud & Guitton, 2017). Augmenting the navigation experience, Google is currently working on an augmented reality feature for Google Maps (Maps AR, 2019). As another example is the startup project Mishor 3D which represents an augmented reality engine for car drivers (Mishor 3D), by rendering virtual signposts and describing texts interpreted from the camera view. The IKEA Place App is yet another example which allows to display and configure specific furniture in your apartment in augmented reality, thus reducing the visit to a furniture shop to visualize how and whether the furniture would fit in its future environment. Despite these, and many more apps in the market, augmented reality is at the time almost without exception used to provide virtual information, with aims to combine with other senses, such as haptic information.

Despite the fact that augmented reality is common for annotating and labelling objects, there isn't much research in the direction of users communicating ideas and collaborating through AR. There are several learning apps which partly achieve the aspect of group interaction—such as in anatomy and mechatronics to train employees with complex machinery in augmented reality (Festo Didactic Augmented Reality App, for example). Although these Apps can be used to teach several people but there is no joint interaction in AR. On the other hand, there is research in collaborating with augmented reality without actual communication. An example of this is the experiment by Vaittinen, Kärkkäinen, and Olsson (2010) describing user experience of annotating different locations in augmented reality, wherein the annotations were placed in a static (i.e. offline) manner. In summary, there isn't much research in augmented reality applications which combine the elements of collaboration, evaluation and discussion, especially in the context of product co-creation and configuration.

2.4 Decision Support for Group Configuration

The group configuration process can be viewed as a sub-scenario of a generic group decision process (Felfernig, Boratto, Stettinger, & Tkalcic, 2018b). In case of conflict resolution and optimizing group outcomes, several theoretical possibilities exist, such as aggregated voting methods (Felfernig, Boratto, Stettinger, & Tkalcic, 2018a). Group recommendations are another promising means to support the group decision-making (Felfernig et al., 2016; Tran et al., 2016), wherein the primary goal of a group recommender is to find an item which takes the preferences of the group members into account. Preferences may be collated using strategies such as aggregated predictions and aggregated models, as described in (Felfernig et al., 2018a), and by using different preference functions like Least Misery or Aggregated Voting.

In the context of cooperative product configuration systems, the subject of workspace awareness also becomes important. As described by Dourish and Bellotti (1992) "an understanding of the activities of others, ... provides a context for your own activity". The actions of a user in a shared workspace need to be made aware of to coordinate his actions with the actions of the other users (Tenenberg, Roth, & Socha, 2016). Although awareness has been a technically challenging requirement to address, the advent of shared XR is opening new doors to address the challenges of preference elicitation, group recommendations, as well as creating awareness of other users' presence and actions. Group configuration decision support may hence be considerably eased by the aspect of awareness creation. In the next section, we discuss the potential and challenges for industrial XR-based group configuration in more detail.

3 Potential and Challenges for Industrial XR-Based Group Configuration

3.1 Design Guidelines for Group Decision and Group Behaviour

Group configuration and buying may be viewed as a co-creation task, where users interact virtually to design and define a product that meets both individual and group preferences. The experience users have with the co-creation system is the key to making virtual places a vibrant source of great connections, creativity, and co-creation (Kohler et al., 2011). Their action research highlights a number of design guidelines that drive collaboration in virtual worlds, immersivity and need to foster informal sociability being two key insights. In online group buying, studies suggest reciprocity, trust, satisfaction, and seller creativity provide considerable explanatory power for intention to engage in online group buying behavior (Shiau & Luo, 2012). Further studying the context of virtual reality with online group buying intention, Tsai et al.

(2011)' findings indicate that perceived usefulness, a sense of virtual community and trust in the virtual community are determinants of purchasing intention. Hence, in tandem with establishing a sense of virtual community, prior work suggest that trust and innovativeness of the seller need to be achieved by design, for creating successful group buying experiences.

3.2 Technical Challenges for Group Configuration in Virtual Reality

A major challenge in the context of real time groupware is the consistency management of the artefact in a shared workspace (Sun, Jia, Zhang, Yang, & Chen, 2018). The main objective is to achieve a consistent view and data for all users. Therefore, the authors in (Sun et al., 1998) defined a consistency model with three properties—convergence, causality preservation and intention preservation.

Several practical and technical challenges exist when moving an existing online configuration to a virtual reality-based configurator: (1) such as establishing a web-based tool for hosting virtual and augmented reality data, (2) moving existing product knowledge across to the VR systems, (3) additional modelling overhead for 3D configurations, (4) achieving compatability with different VR devices, browsers, and systems. However, despite the overheads involved, the benefits outlined earlier, outweigh these resources, thus making a compelling case to involve in extended reality for group configuration.

3.3 Potential for Industrial Applications

In group configuration scenarios a group of users are in charge of configuring a product or service. The main goal in such scenarios is to find a configuration which considers the requirements and preferences from the group, since the end user of such a product is the group in its entirety (Felfernig et al., 2011). In the context of community configuration, Felfernig et al. (2014) presented scenarios which are qualified for group configuration: software release planning with a group of stakeholders, preferences and requirements which need to be assigned to a specific release (Felfernig et al., 2014). Another example is the planning or scheduling of group holiday trips or events, wherein a group of friends have to make decisions about the destinations to visit or the accommodation, that consider a price limit or maximum distance (Felfernig et al., 2018b). Further scenarios are building configuration, stakeholder selection for a new software project, architectural design in software development, financial service configuration and funding decisions (Felfernig et al., 2014).

From a product configuration point of view, there are several B2B use cases that can be readily modelled and augmented by the use of extended reality—specially in cases of industrial production machinery, configuration that is hard to be communicated in terms of text, and sales processes that need the involvement and consenses of different stakeholders (sales teams, engineering teams, production teams, management team, etc. both within and outside an organization). In addition to being a novel marketing channel, and a decision support aid for group products, the visualization of configurations aids to reduce prototyping cycles, and reduces product uncertainty and product returns. Several studies have also highlighted the increased engagement, duration of browsing, conversion and footfall with the use of augmented reality, which can provide a competitive and differentiating edge for the retailers. Reaching out to markets in remote areas might be one of the auxiliary long-term benefits, if virtual reality is combined with web presences in an efficient manner.

Re-engineering the sales process in virtual reality is certainly accompanied by additional overhead (such as visualizing and modelling costs, device compatibility, engineering skills and resources, and identification of viable use cases), which need to be outweighed by the benefits of such a system, in order to make the technological product move towards extended reality.

4 Prototypes

4.1 VR Configurator and Participation Tool

To demonstrate the community configuration in VR, a prototype was developed that presents the concept of the VR configuration and participation tool (Fig. 3). As already analyzed in Sect. 2.2, synchronous methods are well suited for VR-based applications, allowing several users to work together simultaneously in VR. Collaboration takes place locally or in a distributed way.

Since prototyping in VR has been hardly developed and there are no mature tools for creating interactive prototypes, the concept is presented only visually using scenes and storyboards. This helps to determine the usability and user experience of the concept. An Oculus Rift Consumer Version 1 with touch controllers is used to develop the prototype. In order to realistically represent the concept, a practical use case is applied: a zoo enclosure, which can be used for disseminating information in VR. In order to represent the use case close-to-reality, 3D models of the enclosure are modeled using the 3D computer graphics program 3ds Max. The software Sketchbox is used to create the storyboard scenes in VR. Sketchbox also supports the integration of 3D models and 2D graphics. User interface elements are designed in the wireframing and prototyping software Adobe XD and exported as 2D graphics for easy integration into Sketchbox. To make better use of the user's field of view in the virtual world, the interface is bent (Curved UI). In this way, the distance between

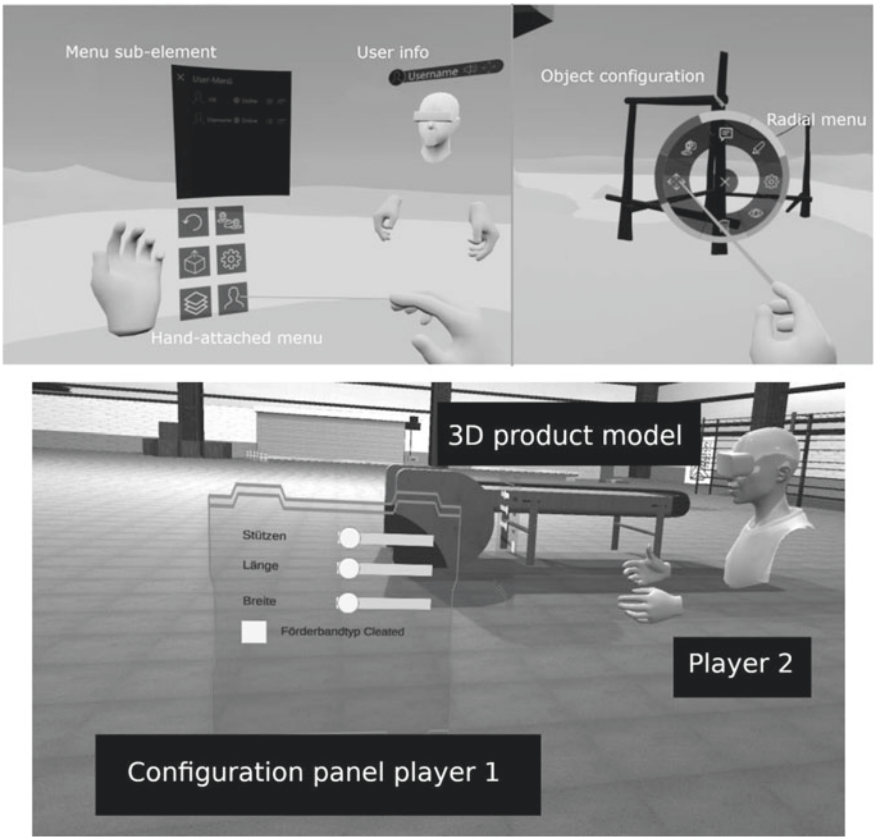

Fig. 3 VR prototype user interface elements

the user and the interface is constant. To implement the Curved UI, the graphics created in Adobe XD are curved and adapted to the virtual world in 3ds Max.

The interaction in VR is divided into the task areas selection, manipulation, navigation and system control (Gerwens, 2017), as well as interpersonal interaction. For navigation in the virtual world the common teleportation technique is used to avoid motion sickness. For selection and manipulation, the so called HOMER technique (Hand-Centered Object Manipulation Extended Ray-Casting) is used, which allows users to select objects by ray-casting and manipulate them by natural hand movements. Hereby the hand is moved to the object position so that the object can be attached directly to the hand (Bowman & Hodges, 1997). HOMER allows the effective selection and movement of remote objects. After selection, a radial menu attached to the object provides options for configuring the selected object. To avoid an accidental movement of the object, the translation must also be activated via the radial menu. General functions such as project settings, object import, navigation, layer menu and user settings are managed via a separate menu that is permanently attached to the user's hand. The menu can be displayed with a hand gesture. Sub-elements of both menus are displayed in the Curved UI style as described above and are attached to the user.

In order to enable a smooth co-creation with several users, awareness of others is important. Therefore, each user's name, profile picture, presence, audio and current activity is displayed in a small screen above the user. The user settings can also be used to update own status (online, away, offline) and to mute individual users so that there is no audio duplication for local collaborations.

In general, the simultaneous manipulation of objects is possible, however, the synchronous configuration of concrete object properties is blocked in order to avoid overwriting the states of different users. Independent properties can be edited simultaneously. If a property is blocked by a user, a warning icon is displayed on the corresponding blocked property in the radial menu for the remaining users.

4.2 AR Annotator

AR-Annotator is a prototype to accomplish a process of annotation, evaluation and discussion of a configured product (i.e. any 3-dimensional object) in augmented reality. The idea behind this is to prototype and enable discussions and feedback on a product model before issuing the start of production by potential customers. Figure 4 summarizes the salient features of the developed prototype.

The AR-Annotator has a generic approach for collaborative working. To be accessible to a large target group, the prototype needs to be readily usable whilst satisfying user friendliness. Augmented reality has the advantage of reaching a larger audience, and feasible to be run on common hardware like current smartphones or tablets. For these reasons, the choice was to develop a smartphone app that can be eventually transported on the SmartWe Platform. The preferred operating system is Android since it is more widely present than iOS globally (Statcounter, 2019), hence consequently limiting the design choice. Another primary augmented reality requirement is the ability to support markerless tracking—to avoid recomputation needs arising due to impact of dynamic environments. The chosen AR-Toolkit is "AR-Core" from Google. ARCore allows developing AR-Apps with markerless tracking. Another advantage is the possibility to integrate ARCore in the Unity 3D IDE, which may be transported easily to Android platforms as well. As a restriction, ARCore is Android native and requires relatively latest hardware (e.g. a gyroscope is necessary) and device version (Supported Devices for ARCore). Following is a description of functions which were implemented in the prototype.

The Prototype has two different views, the camera view and the list view. The list view is just for validation purposes, enlisting all posted annotations without the three-dimensional product model. The camera view represents the linked android camera and allows visual floor detection. The user can touch the visualized floorspace to place a chosen Model with ray tracing on the camera screen. Annotations are displayed in three forms (cubes, spheres or planes). That is so because, many different messages

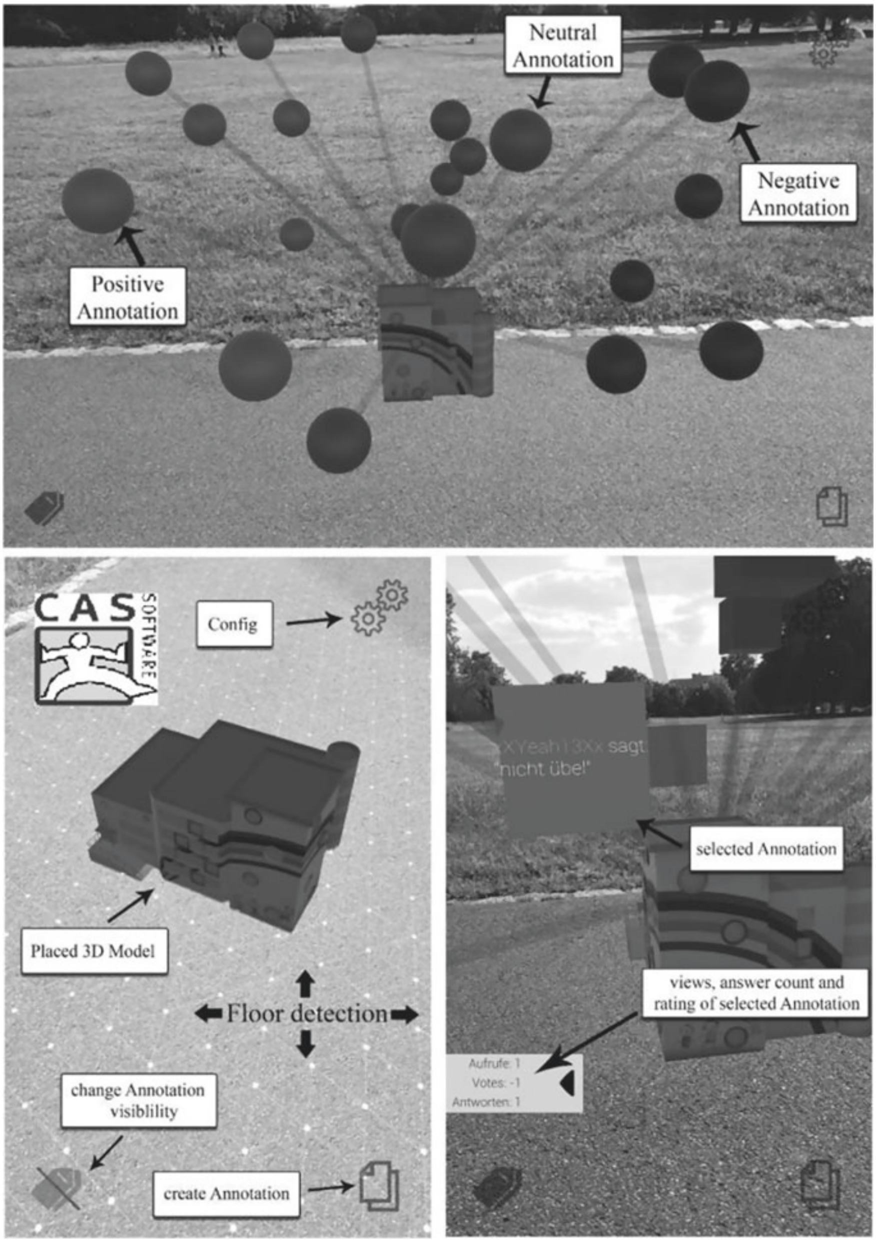

Fig. 4 AR Annotator prototype

are very confusing and indistinguishable in a three-dimensional space. Annotation bodies are coded in three color: negative annotations in red, positive criticism in green and neutral annotations in blue. This evaluation type can be specified in the annotation creation menu where the user can enter their name and formulate a message. The created annotations are then placed depending on reference values to avoid colliding of annotations with one another or with the model itself. It is also possible to sort annotations by the evaluation type on the coordinate system with the model as point of origin. Sorting options for all 3 axes, resizing options for annotations, are also implemented. To select an annotation, its body must fill a specific amount of space and must be completely seen on the camera. If a body is in good view it will be selected automatically. Only one annotation at time can be selected, and the body closest to the camera is selected by default. If the message is too long to be shown, the user can touch the annotation to view the full message and enter discussion mode. In the discussion mode annotations from other users can be viewed and replied to. Every annotation has constantly updating key figures (views, answer count and rating) to analyse the annotation lifecycle.

The described features in the AR Annotator tool hence facilitates group discussion and sharing of specific configuration ideas, as well as can be used to obtain votes, and mine opinion on configuration variants, as is often desired in customer and sales management across different stakeholders (customers, product designer, sales executive, manufacturing units) in group product configuration scenarios.

5 Evaluation and Design Implications for XR-Based Group Configuration

In order to determine the suitability of the VR configurator & participation tool concept, the prototype is evaluated using an evaluation questionnaire. The questionnaire consists of a Likert scale and open-ended format questions. In general, the clarity of the concept, its usefulness, the appropriateness of the task load, as well as the overall impression and attractiveness of the design were evaluated. Other questions were specifically related to the virtual world. Besides the degree of immersion, the design of the UI elements in VR and their readability were questioned. Furthermore, the test persons were asked about their reaction to the virtual world regarding VR Sickness. Well-established questionnaires, such as Questionnaire User Interface Satisfaction (QUIS), System Usability Scale (SUS), Simulator Sickness Questionnaire (SSQ), NASA Task Load Index (NASA-TLX) and Presence Questionnaire (PQ), were used as a reference for the creation of the used questionnaire.

The AR functions of the prototype must be evaluated by different people to improve the collaborative usage—specially to verify whether users actually use the discussion function to collaborate with each other. Furthermore, it should be clarified which mode of interaction is preferred, camera view or list view. Both the AR &

VR app were tested by a representative sample of upto 10 users (typical for usability tests), ranging from students to the company's employees, ensuring balanced demographics in terms of gender, age, and having atleast three different domains of expertise. After that the test persons shall evaluate with a prepared System Usability Scale (Brooke, 1996) to share their experiences. The gained user experience will then be used to adjust the prototypes and improve its intuitiveness and ease of use for the group configuration scenario.

6 Discussion and Future Work

A first prototype in VR and AR, for addressing the group product configuration problem has been developed. Several extensions are possible, such as switching from one mode to the other, testing efficacy across consultative and collaborative scenarios, and testing across different product configuration scenarios. Although the potential for group configuration scenarios remain high, the move towards virtual reality will have to be evaluated on a case by case basis, where the visualizing is an absolute necessity in the group configuration process. For instance, group planning scenarios (such as appointments, travel, project or software development planning), may be resolved without high 3D visualization tools, whereas group product creation can be highly enriched by extended reality experiences.

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"I See Myself, Therefore I Purchase": Factors Influencing Consumer Attitudes Towards m-Commerce AR Apps

Mafalda Teles Roxo and Pedro Quelhas Brito

Abstract Mobile commerce (m-commerce) is starting to represent a significant share of e-commerce. The use of Augmented Reality (AR) by brands to convey information about their products—within the store and mainly as mobile apps—makes it possible for researchers and managers to understand consumer reactions. Although attitudes towards AR have been studied, the overall effect of distinct aspects such as the influence of others, the imagery, projection and perceived presence, has not been tackled as far as we know. Therefore, we conducted a study on 218 undergraduate students, using a pre-test post-test experimental design to address the following questions: (1) Do AR media characteristics affect consumer attitudes towards the medium in a mobile shopping context? Also, (2) Do the opinion and physical presence of people influence the attitude towards an m-commerce AR app? It found that AR characteristics such as projection and imagery positively influence attitudes towards m-commerce AR apps, whereas social variables did not have any influence.

Keywords MAR · m-commerce · Consumer psychology · AR-consumer relationship

1 Introduction

Simultaneously with the increasing percentage of e-commerce sales resulting from mobile retail commerce (m-commerce), it is estimated that in the U.S., by 2020, 49.2% of online sales will be made using mobile apps (Statista, 2019b). Also, in 2018, approximately 57% of internet users purchased fashion-related products online (Statista, 2019a).

Several factors have contributed to the rise of m-commerce, such as the increased computing capacity of mobile devices, the fact it saves time and money, and the

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inclusion of technological innovations that create new ways to present products (Beck & Crié, 2018; Pantano & Priporas, 2016). Thus, the incorporation of technology like Augmented Reality (AR) leads to a whole new retail experience, primarily through the development of m-commerce AR apps (Dacko, 2017).

AR is a point on the Virtual Continuum where 3D computer-generated artefacts are overlaid on the real environment to enable blending of the real and virtual worlds (Azuma, 1997; Milgram, Takemura, Utsumi, & Kishino, 1994; Schmalstieg & Hollerer, 2016). Thus, AR can enhance our perception of reality by augmenting both the product (within a marketing context) and the environment (Preece, Sharp, & Rogers, 2015). This enhancement of reality can be achieved through different devices, such as handheld displays (e.g. smartphones, tablets), head-mounted displays (HMD, e.g. smartglasses) or special displays (Carmigniani et al., 2011).

In order to comprehend the increasing incorporation of Mobile Augmented Reality (MAR) into company marketing strategies, we need to understand which factors influence consumers the most while using this technology. Additionally, studies regarding the use of m-commerce AR apps within the context of a social event are scarce.

Therefore, drawing on the theories related to the media characteristics inherent in AR, namely those focusing on augmentation and presence (Javornik, 2016a, 2016b; Verhagen, Vonkeman, Feldberg, & Verhagen, 2014), as well as on theories related to social influence (Borges, Chebat, & Babin, 2010; Lee, Shi, Cheung, Lim, & Sia, 2011), we explore how these factors affect consumer attitudes towards m-commerce AR apps. Specifically, we aim to address the following questions:

RQ1: Do AR media characteristics affect consumer attitudes towards the medium in a mobile shopping context?

RQ2: Do the opinion and physical presence of people influence attitudes towards an m-commerce AR app?

To answer these questions, we structured this study as follows: we review the literature on AR and its augmentation affordance; the usability of new technologies, and the social factors that influence the use of an m-commerce AR app. We then present our experimental design, followed by the results of the logistic regression and a discussion of the results.

2 Literature Review

2.1 Acknowledging Augmented Reality

Past research on the acceptance of AR technology focused on three main themes: (a) Acceptance of smart glasses (i.e. wearable computer glasses); (b) MAR; (c) AR marketing effectiveness.

Acceptance of smart glasses

Smart glasses are a type of portable AR solutions. Due to their inherent characteristics, several authors studied their emergence from different perspectives. For instance, to explain the adoption and use of smart glasses, we can focus on the Big Five Model of Human Personality (Rauschnabel, Brem, & Ivens, 2015), the Technology Acceptance Model (Rauschnabel & Ro, 2016), or the Uses and Gratifications Theory (Rauschnabel, 2018). People who displayed extraversion and openness traits were more likely to adopt smart glasses, whereas those who score higher on neuroticism were less prone to adopt such devices (Rauschnabel et al., 2015). Moreover, the degree of technology innovativeness was found to be a predictor of the use of smart glasses, whereas social norms were relevant for the consumer's intention to adopt these devices, despite not being related to consumer attitudes towards the use of smart glasses (Rauschnabel & Ro, 2016). Regarding the Uses and Gratifications Theory, Rauschnabel expanded the current literature by developing a framework that considers six gratifications derived from the use of smart glasses, with a particular emphasis on the need to enhance reality, as well as the segmentation of the context of private versus public use (Rauschnabel, 2018).

MAR

The sophistication of the computational power and sensors of mobile devices, the ubiquity they offer, and the 24/7 Internet access they provide, made them the perfect target for developing mobile AR apps (MAR). MAR differs from the Azuma's 'traditional' definition of AR because the MAR system runs and/or displays the 'new reality' on mobile devices, such as smartphones or tablets (Chatzopoulos, Bermejo, Huang, & Hui, 2017). Further research focused on the User Experience (UX) found that a good UX of an AR mobile app leads to more positive experiences, thus increasing emotional engagement, and that this UX is affected by characteristics intrinsic to the technology itself (Dirin & Laine, 2018; Olsson, Lagerstam, Kärkkäinen, & Väänänen-Vainio-Mattila, 2013).

Additionally, Dacko focused his research on the use of MAR as part of a smart retail environment. He found that MAR apps offer extrinsic benefits, which are highly valued by app users (Dacko, 2017). Moreover, MAR apps offer more benefits than those offered during a shopping experience, and they leverage retail setting evaluations, which add experiential value to the retail setting (Dacko, 2017).

AR marketing effectiveness

Past research focused on understanding whether AR was a useful tool for marketing purposes. Therefore, there are studies analysing the impact of the incorporation of AR technology on e-commerce websites. These found that the perceived ease of use, perceived usefulness and perceived enjoyment of the system promotes an attitude that leads to the adoption of AR technology, which consequently affects the behavioural intention of AR usage (Pantano, Rese, & Baier, 2017). Moreover, when comparing a technical aspect of AR, namely the tracking techniques, Brito and Stoyanova found that the use of a markerless AR system outperforms the marker-based one (those that need a fiducial and tangible marker to create the AR experience) when comparing brand recommendation intentions (Brito & Stoyanova, 2018).

2.2 Perception of Augmented Product

The definition of AR relates to the ability of this technology to expand the real environment interactively and in realtime with 3D computer-generated data (Azuma, 1997). This 'data' that can be overlaid to the real-world can come from a variety of sources, namely, images, videos, texts, and haptics (Craig, 2013; Roxo & Brito, 2018). With the advent of MAR, companies started to develop mobile apps that superimpose commercial products, such as make-up (e.g. L'Oréal), sunglasses (e.g. Ray-Ban), or even furniture (e.g. IKEA), on the real environment.

Drawing on the study conducted by Laroche and colleagues (2005) on the link between intangibility and difficulty of evaluation and perceived risk in an online shopping context (which lacks physical tangibility), we adapt their concept of intangibility to the AR context. Therefore, we define 'projection' as a concept that grasps the ability to augment the presence of a product (making it more tangible) using an AR visualisation. Thus,

H1: *AR Projection will positively influence consumer attitudes towards the use of m-commerce AR apps.*

Traditionally, imagery is "a mental event involving visualisation of a concept or relationship" (Lutz & Lutz, 1978, p. 611), which can be elicited by a pictorial or verbal stimulus, or by inducements (Lutz & Lutz, 1978).

In this study, we follow the definition offered by Bone and Ellen, who consider imagery as "the clarity with which the individual experiences an image" (Bone & Ellen, 1992, p. 96). This is similar to the conceptualisation of vividness used by Yim, Chu, and Sauer (2017). In their study, Yim and colleagues found that vividness generates positive consumer evaluations that will impact media immersion. Therefore, as AR can enrich the environment with pictorial stimuli, it creates a sense of presence/mimics the real experience of the product (Rodríguez-Ardura & Martínez-López, 2014; Roggeveen, Grewal, Townsend, & Krishnan, 2015). Therefore, the way users perceive the quality of the augmented product (in this case sunglasses) will affect their attitudes towards the AR app.

H2: *Imagery will positively affect consumer attitudes towards MAR Apps.*

2.3 Perception of Environmental Augmentation

Augmentation can be defined as the ability of AR to add additional virtual and dynamic capabilities/content to real systems (Billinghurst, Clark, & Lee, 2014).

Despite this inherent characteristic of AR, which enriches the real environment by blending both the virtual and the real, few studies have focused on this feature. Javornik devoted her attention to understanding whether the use of AR generated perceived augmentation, i.e., the way the self psychologically processes the environment enhancement. She found that its effects on subjects' affective and cognitive responses were mediated by flow (Javornik, 2016b). However, a link between perceived augmentation and the subjects' attitude towards AR is a topic that has yet to be studied. Therefore,

H3: *Perceived Augmentation positively influences consumer attitudes towards the use of m-commerce AR apps.*

When in a Mixed Reality (MR) context, the subject experiences object presence or the sense of being somewhere else through a computer-mediated environment (Steuer, 1992). Drawing on the notion of Klein's telepresence and Verhagen and colleagues' local presence definition, we conceptualise perceived presence as the way that the self positions itself within an MR context, i.e. whether the person feels (s)he is closer to the real or the virtual environment (Klein, 2003; Verhagen et al., 2014). Verhagen and colleagues found that new ways of presenting products reinforce the likability and tangibility of products, which leads to purchase intention (Verhagen et al., 2014). However, they did not find any link between presence and behavioural intentions.

H4: *Perceived Presence positively impacts consumer attitudes towards the use of m-commerce AR apps.*

2.4 Technology Usability

The Technology Acceptance Model proposed by Davis explains users' acceptance of technology according to two dimensions: ease of use (EoU) and usefulness (Davis, 1989). Ease of Use expresses the degree to which a user feels (s)he can use a system/technology effortlessly, and this can be due to a good user interface, whether the system is intuitive or not, and so on (Davis, 1989).

Past research did not find a direct link between EoU and attitude (Kim & Forsythe, 2008). However, a comparison between German and Italian samples found a positive association between EoU and users' attitudes towards the adoption of AR systems for the German sample (Pantano et al., 2017).

H5: *Perceived Ease of Use of the app will positively influence users' attitudes towards the use of m-commerce AR apps.*

2.5 Social Influence

Shopping is perceived as a social experience (Falk & Campbell, 1997; Tauber, 1972), influenced by friends, family and reference groups—social influence. Conversely, in the paradigm of Web 2.0 and social media, the influence that others might exert over consumption decisions is even more relevant (Bilgihan, Kandampully, & Zhang, 2016). However, manifestations of this phenomenon are not evident within the context of mobile shopping. Past research highlights the fact that shopping with friends is positively associated with the companion effect and hedonic shopping values, as compared to shopping alone or with relatives (Borges et al., 2010). In addition, it was found that the link between attitudes towards online shopping and the intention to purchase online is reinforced by the role of strangers as sources of social influence (Lee et al., 2011). Moreover, younger adults place a higher value on the opinions of others, such as reviews posted by ordinary people (as in Amazon), influencers and bloggers (Pantano & Gandini, 2018). Therefore, we anticipate that consumers rely on others' opinions when shopping in mobile platforms, whether they are companions (family, friends, peers) or strangers (such as influencers), and that consumers are willing to voice their opinions.

H6: *The opinion of others will positively affect consumer attitudes towards AR apps.*
H7: *The presence of acquaintances when using the AR app will influence attitudes towards AR.*
H8: *The presence of strangers when using the AR app will influence attitudes towards AR.*
H9: *My willingness to express an opinion when my acquaintances try the app will positively influence attitudes towards the use of m -commerce AR apps.*
H10: *My willingness to express an opinion when strangers try the app will positively influence attitudes towards the use of m -commerce AR apps.*

3 Method

3.1 Participants

A total of 218 university students in the North of Portugal participated in the experimental design. Once in the lab, they were asked to interact with an AR app installed on tablets. The average age of the participants was 19.62 ($SD = 2.285$), 68.0% were female, and 60.7% were Portuguese (the remaining 39.3% were Portuguese speakers). College students are an age group and educationally homogenous group which is more prone to try new technologies like AR, and more experienced in purchasing fashion items online than older people (Owyang, 2010; Priporas, Stylos, & Fotiadis, 2017; Zhitomirsky-Geffet & Blau, 2016).

3.2 Stimuli

We selected sunglasses as the product for the experiment because they are products students perceive as relevant, and they are likely to buy them (product involvement: M = 4.03, SD = 1.891; Zaichkowsky, 1985).

3.3 Procedure

Firstly, the students agreed to take part in the study. Then, they were randomly assigned to the experimental condition (Malhotra, Nunan, & Birks, 2017): (1) using the mobile app alone, with no external interference (n = 54); (2) using the app alone, with external interference (n = 24); (3) using the app accompanied, with no external interference (n = 58); (4) using the app accompanied, with external interference (n = 82).

We used the EVO Sunglasses AR mobile app (downloaded from Play Store) and installed it on the tablets. The participants were asked to browse the app and to try one to three sunglasses models for 5 min. This time frame was set after several pre-tests and in line with similar designs (Brito & Stoyanova, 2018).

3.4 Measures

This study was a pretest-posttest experimental design (Malhotra et al., 2017). As pre-test measurements, we asked the participants questions about their demographic data and product involvement (Zaichkowsky, 1985). After interacting with the app, we asked the participants about the media characteristics of *perceived* augmentation (adapted from Javornik, 2016a), *perceived* presence (Klein, 2003; Verhagen et al., 2014); *projection* (adapted from Laroche, Yang, McDougall, & Bergeron, 2005), *ease of use* (Davis, 1989). We asked participants about the *imagery* (adapted from Bone & Ellen, 1992), and their attitude towards the AR app (Yim et al., 2017). We further questioned them on the importance they attribute to the opinions of others when using a mobile AR app, the influence they are able to exert on others, and vice versa. All the measurements were built on 7-point Likert scales, except Attitude towards the AR app, which was a 5-point Likert scale.

The reliability test values (Cronbach alpha) for the variables were acceptable ($0.711 \leq \alpha \leq 0.828$) (Hair, Black, Babin, & Anderson, 2014; Nunnally & Bernstein, 1994).

Logistic Regression

Logistic Regression is a data analysis technique used to fit a logistic model relating a binary/dichotomous outcome variable to explanatory/independent variables (Cox &

Table 1 Summary of the variables and respective hypothesis

Model	Variable name	Hyp.
Dependent Variable (DV): attitude towards AR[a]	ATT	
Projection Imagery	Proj_AR IMG	H1 H2
Perceived Augmentation Perceived Presence	PAug PercPres	H3 H4
Ease of Use	EoU	H5
Importance of others' opinion about the app	ImpOut	H6
Influence I can exert on others while using the app	Influenc1 Influenc2	H7 H8
Influence others can exert on me while using the app	Influenc4 Influenc5	H9 H10

[a]The DV was coded as 1 = positive; 0 = negative attitude

Snell, 1989; Hosmer, Lemeshow, & Sturdivant, 2013). This model is often used to study the likelihood of an observation that belongs to a particular group (Malhotra et al., 2017).

In this model, the response of the individual took one of two possible values: 0 = negative; 1 = positive attitude towards m-commerce AR apps. All the model variables are listed in Table 1.

We considered gender and the experimental condition as independent variables, they were set as contrasts indicators.

4 Results

Table 2 shows the results of our model.

As a measure of the model fit, we use the Pseudo R^2 variation introduced by Nagelkerke, where the higher the value, i.e., the closer to 1, the greater the model fit (Hair et al., 2014). Nagelkerke R^2 was preferred over the Cox & Snell R^2 because it gets round the fact that the latter cannot equal 1.0, even when the model fit is perfect (Malhotra et al., 2017). Therefore, our model explained 54.6% (0.546) of the variance in the attitude towards AR (based on Nagelkerke R^2). Despite the fact that the measures of model fit fell somewhat short of the levels of predictive accuracy achieved by this estimation method, the overall per cent of cases that it correctly predicted was 81.7%.

The variables that contributed most to a positive attitude toward m-commerce AR apps were Projection and Imagery, therefore supporting H1 and H2. Moreover, Projection and Imagery showed odds-ratio greater that one, meaning that the attitude towards an m-commerce AR app exerts a stronger influence on the perception of the augmented product.

Table 2 Results of the binary logistic regression

Parameter	Estimate	S.E.	Wald χ^2	Sig.	Odds-ratio
Experimental Condition (M3PInter)			4.117	0.249	
M3PInter1	0.002	0.508	0.000	0.998	1.002
M3PInter2	**−1.204**	**0.635**	**3.590**	**0.058#**	**0.300**
M3PInter3	−0.288	0.496	0.337	0.562	0.750
Gender (Gen)	0.112	0.409	0.075	0.785	1.118
Projection (Proj_AR)	**0.922**	**0.221**	**17.486**	**0.000***	**2.515**
Imagery (IMG)	**0.573**	**0.276**	**4.296**	**0.038***	**1.774**
Perceived Augmentation (PAug)	0.041	0.308	0.018	0.894	1.042
Perceived Presence (PercPres)	0.200	0.254	0.620	0.431	1.221
Ease of Use (EoU)	0.088	0.194	0.207	0.649	1.092
Importance of others' opinion about the app (ImpOut)	−0.142	0.186	0.585	0.444	0.867
Influenc1	0.148	0.163	0.826	0.363	1.160
Influenc2	−0.125	0.181	0.479	0.489	0.882
Influenc4	0.013	0.180	0.005	0.943	1.013
Influenc5	0.230	0.183	1.574	0.210	1.258
Constant	−9.135	2.204	17.183	0.000	0.000
Model Fit Statistics					
−2LL	179.259				
Cox & Snell R^2	0.403				
Nagelkerke R^2	0.546				
% Correct predict/obs.	81.7				

Notes #Significant at 10% level; *Significant at 5% level; χ^2 = 112.297; 14 df

5 Discussion and Conclusion

In this study, we investigate the impact of several factors related to AR, as well as those associated with a social shopping experience. The former refers to the ability to augment a product in order to enrich reality, and the effortlessness of using the technology. The latter involves the importance of others, the impact of their presence, and a willingness to express their opinion within a purchasing context.

Our findings support H1 and H2 and do not support H3–10 (see Table 3). Moreover, we found a positive relationship between experimental condition 3 (using the app accompanied, with no external interference) and the attitude towards use the of an MAR app.

The empirical results support the fact that product augmentation (in this case sunglasses) to a certain extent reduces the sense of intangibility, and therefore promotes a positive attitude towards the use of these kinds of m-commerce apps. The same rationale can be established for the perception subjects have of a pictorial stimulus

Table 3 Summary of the results of the hypothesis

Hypothesis		Result
H1	Projection → attitude towards use MAR App	Supported
H2	Imagery → attitude towards use MAR App	Supported
H3	Perceived Augmentation → attitude towards use MAR App	Not supported
H4	Perceived Presence → attitude towards use MAR App	Not supported
H5	Ease of Use → attitude towards use MAR App	Not supported
H6	Others' Opinion → attitude towards use MAR App	Not supported
H7	Physical Presence acquaintances → attitude towards use MAR App	Not supported
H8	Physical Presence strangers → attitude towards use MAR App	Not supported
H9	Willingness to give an opinion to acquaintances → attitude towards use MAR App	Not supported
H10	Willingness to give an opinion to strangers → attitude towards use MAR App	Not supported

such as an AR-based image. This means that the superimposition of 3D computer-generated artefacts enabled by AR, and the perception of the quality of such augmentation, favour the adoption of AR technology in e&m-commerce, especially when increased interactivity and vividness are considered (Yim et al., 2017).

Regarding the influence of the ability of AR to enrich reality, and the induction of this enhanced reality on the self, we did not find any empirical evidence to support its impact on consumer attitudes towards the use of m-commerce AR apps. Our results might reflect the fact that the effect of perceived augmentation is mediated by flow, a variable that we did not take into consideration in our own model (Javornik, 2016b). Also, the lack of support for H4 might be because we investigated the impact of perceived presence on attitudes towards m-commerce AR apps, rather than purchase intention. These findings somehow contradict the study by Klein (2003), who found that higher levels of telepresence lead to more intense attitudes towards the advertised product. The difference in our results might be explained by the fact that we studied an m-commerce app, rather than an advertisement.

Concerning the link between ease of use and attitudes, our results are in line with those of Pantano and colleagues for the Italian sample of their study (Pantano et al., 2017), which might be due to some cultural influence.

Regarding the lack of support found for the hypothesis relating to social influence (H7–10), this might be related to the fact that young consumers prefer shopping to be an individual activity, rely on friends when needed, and regard intervention by the salesperson with caution (Pantano & Gandini, 2017).

6 Conclusions and Future Research

In this study, we tried to understand if the attitude towards m-commerce AR apps is influenced by AR characteristics, and by the physical presence of other people. Regarding the media characteristics, we found that both Projection and Imagery had a positive influence on the attitude towards m-commerce AR apps. We found that Perceived Augmentation, Perceived Presence, and Ease of Use did not prove to be significant among our sample, which might be because they could be mediators between Projection or Imagery and the Attitude towards the medium. In a future study, other variables could be added as mediators and/or moderators, such as flow or interactivity.

Another finding of our research was that, contrary to what we expected, social influence did not play a significant role within the context of m-commerce. This finding could be due to the sample used, undergraduate students aged between 17 and 22 years. Thus, further research is needed to reframe the concepts of social influence studied, and well as extend this research to other age groups, both younger (Thaichon, 2017), and older (Drolet, Jiang, Pour Mohammad, & Davis, 2019).

An aspect that deserves further investigation is the link between the attitude towards m-commerce AR apps, and a self-reported measure of purchase intention, as well as to attempt to establish a link between variables such as augmentation and presence and the physiological state of the subjects.

Besides these theoretical contributions, this research provides managers with useful insights into which aspects of MAR interaction could be better designed to meet consumers’ needs and expectations.

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Consumers' Emotional Response to the Use of Augmented Reality (AR): An Exploratory Study

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Abstract Most of the empirical studies on augmented reality (AR) in marketing have focused primarily on the cognitive perspective. Considering only a handful of research on AR in consumer behaviour include emotion variables, this paper aims at exploring consumers' acceptance toward AR application by identifying emotions associated with the use of AR application. A multi-method design is selected for the study in order to gain rich insights. From the focus group interviews, consumers' emotions associated with AR application are explored. Emotions, attitude, desire and intention related themes are identified. Based on these themes and participants' socio-psychological characteristics obtained using a structured format during the focus group, a set of propositions related to consumers' acceptance towards AR application are presented. A conceptual framework for empirical validation is proposed for a subsequent study.

Keywords Augmented reality · Emotions · Focus group · Technology acceptance · Multi-method

1 Introduction

It was not until recently that marketers realised the importance of augmented reality (AR) in retail settings (Pantano, Rese, & Baier, 2017). Cosmetics companies such as Sephora and Estee Lauder introduced an AR enabled mirror that enables customers to try out virtual facial makeup, while other companies such as Ikea, Tissot, Ray-Ban,

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etc. have been incorporating various forms of AR to enhance consumers' experience with their products. Other than enhancing shopping experience through precise customisation and virtual try-on, AR is able to provide a richer and more interactive retail experience to influence consumers' purchase decision (Olsson, Lagerstam, Kärkkäinen, & Väänänen-Vainio-Mattila, 2011; Pantano et al., 2017; Poushneh, 2018). Since there are many tangible benefits AR can offer to consumers; retailers may expect AR to be part of their purchasing process. Despite its importance, the impact of AR on consumer behaviour is relatively unknown. Although research on AR has increased tremendously in the recent years, there is little investigation on consumers' feelings and emotions associated with AR applications.

2 Theoretical Background

Marketing scholars have focused primarily on cognition to understand consumer behaviour (Bagozzi, 1997). Beaudry and Pinsonneault (2010) commented that research has neglected emotions which are important drivers of behaviours. They also claimed that research hitherto has only studied a limited number of emotions in studies related to information technology use. As stated by Kulviwat, Bruner, Kumar, Nasco, and Clark (2007), consumers' feelings and thoughts with regards to technology acceptance should be considered in consumer contexts.

Most of the empirical researches related to AR in marketing have focused primarily on the cognitive perspective. In the existing literature, there are only two studies which included emotions or affective responses pertaining to AR in retailing. The first, Poncin and Ben Mimoun (2014) examined the effect of in-store technology, including a magic mirror enabled by AR, on consumers' holistic perception of the store atmospherics. Secondly, Javornik (2016) investigated two AR apps and the differences in consumer responses to media characteristics of AR. No comprehensive study to investigate consumers' emotions associated with AR usage. Besides, only few affective variables related to AR have been studied in the similar context. These include perceived enjoyment (Pantano et al., 2017; Rese, Baier, Geyer-Schulz, & Schreiber, 2017; Rese, Schreiber, & Baier, 2014; Yim, Chu, & Sauer, 2017), entertainment/playfulness (Dacko, 2017; Huang & Liao, 2015; Huang & Tseng, 2015; Yaoyuneyong, Foster, Johnson, & Johnson, 2016), novelty (Poushneh & Vasquez-Parraga, 2017; Yaoyuneyong et al., 2016; Yim et al., 2017), curiosity (Beck & Crié, 2018) as well as irritation (Yaoyuneyong et al., 2016).

Considering only a handful of studies related to AR in consumer behaviour included socio-psychological variables such as emotions, values, and social influence, this paper aims at exploring consumers' reactions towards AR applications by identifying emotions associated with the use of AR applications. From an implication standpoint, the emotions under investigation in this study will be of importance in explaining consumer behaviour associated with AR and have potential to provide insights for marketers in terms of enhancing interaction and brand association.

3 Methodology

To explore consumer's emotions evoked by the use of AR based apps, a multi-method approach is used in this study. Focus group interviews were conducted because of its suitability for exploratory research (Calder 1977).

3.1 Focus Group Interview Procedure

The researchers conducted three focus groups with 6 participants in each group. Each session lasted for about 60 min. The researchers first explained the objective of the study and introduced the general idea of mobile AR application to the participants of each focus group. The participants were then asked about their feelings toward the concept in general. Next, the researchers guided all participants to download and install the AR application called "Sephora—Beauty Shopping" on their smartphone and gave a brief introduction about this AR application. Again, the participants were asked to share their initial responses toward the newly installed application. After that, they were given 10 min to explore the App and asked to choose any shades of makeup for eyes or lips by clicking "Try this shade" button available on the app. After the exploration of the application, the researchers probed participants for their emotional responses and interviewed the participants based on a set of questions. Subsequently, the participants were asked more concrete questions about their attitude and intention to use the AR application. After the interview, the participants completed a short questionnaire on their background, personality traits and values. The researchers assessed the participants' personality traits and values because it would be interesting to find out whether these traits and values would have any impact on their emotional responses and attitude towards using the application. Personal innovativeness, materialism and hedonism are among the traits and values the researchers attempted to examine.

3.2 Participants

As Sephora virtual mirror is available only for makeup category, female participants were invited for participation in the focus group discussions. Female executives and administrative staff working in a private higher educational institution were contacted via phone to gather responses on their interest to take part in the focus group interview. Participants from the three age groups i.e., 21–30, 31–40, and 41–50 were invited for different interview sessions. For the first age group (21–30), majority of the participants were found to be hedonic consumers and were reported to be very innovative but not materialistic. By contrast, most of the participants in the second age group (31–40) reported to be moderately innovative, hedonic consumers, and more materialistic. For the third age group (41–50), most of them were found to be utilitarian consumers, slightly materialistic, and not as innovative as the participants of the previous groups.

4 Analysis and Discussion

The audio recordings of the three focus group interviews were transcribed and coded. Based on the review and analyses of the full transcription prepared from the audio recordings, a list of key ideas and verbatim quotes were identified for category formation (Zemke & Kramlinger, 1982). This analysis was then reviewed by another researcher who played an auditor role to ensure all the ideas are drawn in unprejudiced manner (Hirschman, 1986). The most repeated words and ideas were identified and clustered into codes upon thorough and systematic analysis. The title of the code was decided using relevant information found in the extant literature. For instance, for the definition categories of emotions, work by Kleinginna and Kleinginna (1981) was used to generate codes and were then transformed into the theme titled as "emotions". In similar fashion, the most relevant themes including emotions, attitude, desire and intention were identified as shown in Table 1.

4.1 General Observation

When comparing the emotional responses among the three age groups, it was found that the 41–50 age group showed the least interest in the AR application. Almost all the participants in this age group insisted to try and purchase the product from the physical store. It seems that the touch and feel part is still indispensable for them. On the other hand, the 31–40 age group appeared to be the most interested in using the AR application. They spent much more time in exploring the application compared to other age groups. It was observed that they were very excited and joyful throughout the 15 min of using it. They showed many positive emotions and very positive attitude towards using the app. Surprisingly, the participants in the youngest age group (21–30) were not too excited during the use of the application. Perhaps, they are either still at the early stage to use cosmetics products or they are used to such AR enabled applications. Later is more likely because of their habitual use of applications such as Snapchat, Instagram and the likes which have AR functions.

Generally, all participants were willing to try using the application, ranging from mild to very strong desire, except for few in 41–50 age group. Majority also indicated moderate to high intention to use the application when they are planning to purchase facial cosmetics. Clothing, hairstyle, glasses, furniture, and even counselling are among the other types of products or services the majority said they would like to purchase via AR application.

Table 1 Generated themes from focus group interview

Themes		Codes	Respondents' words		
			Age group 21–30	Age group 31–40	Age group 41–50
Emotion	Emotional responses prior to installation of the AR app	Affective	–	–	Excited
		Cognitive	Distracted, curious	Curious	Curious
		Physiological	–	–	–
		Expressive	–	–	–
		Adaptive	Hindrance	–	–
		Motivational	Interested	–	–
	Emotional responses upon installing the AR app	Affective	No excitement	Excited, attracted	Bored
		Cognitive	Normal	Useful, easy to navigate	Attractive
		Physiological	–	–	–
		Expressive	Nothing surprising	–	–
		Adaptive	–	–	–
		Motivational	Interested	–	–
	Emotional responses after using the AR app	Affective	Excited, joyful, fun	Distressed, excited, fun	Joyful, entertaining, Fun
		Cognitive	Useful, curious	Clever system, troubled	Useful
		Physiological	Interactive	Overwhelmed	–
		Expressive	Surprised	Engaging	–
		Adaptive	Control and freedom	–	–
		Motivational	interested, inspired	–	–
Attitude		Usefulness	Useful	Useful to select colour	Useful and helpful
		Entertainment	More for pleasure	Fun	–
		Convenience	Convenient	–	Save time, for busy people
		Informativeness	Many colours are shown	–	Additional information

(continued)

Table 1 (continued)

Themes		Codes	Respondents' words		
			Age group 21–30	Age group 31–40	Age group 41–50
Desire		Product selection	Can choose different colours	Search for more options	Select online but buy offline
		Comparison	–	Can compare shades	–
		Product search	–	Can search for more products	–
Intention		Urgency	Use only when free	Use when needed	–
		Touch and feel	–	Prefer physical store	–
		Decision making	–	–	Help to make decision

4.2 Proposition Development

Based on the themes identified from the analyses of the focus group interviews, a set of propositions related to consumers' acceptance towards of AR application is created.

Exposure to the AR applications evoked emotions among the participants of our study. These emotions included both positive and negative emotions which then influenced their attitude towards using the application. It seems that the felt emotions mediate the relationship between exposure to the AR application and attitude towards using the application. The findings also showed that participants who felt more positive emotions tend to have more positive attitude towards using the application. Based on these observations, the researchers would like to propose the following:

P1: The positive emotions felt by consumers as a result of using AR application positively influences their attitude towards using the AR application.

Examination of the participants' personality traits and values revealed that different participants showed varied attitude towards using the AR application. Hedonic users showed more positive emotions and positive attitude than less hedonic users. It might be due to the fact that hedonic users tend to seek more fun and appreciate entertaining features provided by the application. Kim and Forsythe (2007) also reported that hedonic motivation is positively related to the attitude towards using product virtualisation technologies whereas Childers, Carr, Peck, and Carson (2001) reported that the hedonic aspect is as essential as utilitarian aspect for prediction of attitude in online context. Hence, it is proposed the following:

P2: The greater the hedonic tendency, the greater will be the influence of felt emotions on attitude towards using AR application.

Participants, who scored higher in materialism, showed more positive emotions and positive attitude towards using the application. This finding is consistent with Richins' (2012) study in which he reported consumers with high materialistic tendency show more positive product-evoked emotions compared to consumers with low materialistic tendency. Since Richins (1994) revealed that materialistic consumers tend to value possessions that enhanced their image, the researchers argue that consumers with high materialistic tendency would show more positive emotions towards using the AR enabled apps. Above lines of reasoning leads to the below proposition.

P3: The greater the materialism, the greater will be the influence of felt emotions on the attitude towards using AR applications.

Innovative participants were found to have more positive emotions and positive attitude toward using the application. The researchers also found that utilitarian participants are less interested in the application while hedonic participants are excited with the application. Generally, innovative consumers are likely to form positive attitude towards new technology or innovation. Argawal and Prasad (1998) also demonstrated that personal innovativeness has significant moderating influence on consumers' perceptions of a new technology. Hence, it is expected that the influence of felt emotions will be moderated by personal innovativeness.

P4: The greater the personal innovativeness, the greater will be the influence of felt emotions on the attitude toward using AR applications.

Next, most of the participants who showed a positive attitude towards using the application appeared to have stronger desire to use it. Further, their desire to use might have activated their intention to use. These participants who showed stronger desire to use the application are more inclined to use the application in future. Hence, the following are proposed:

P5: Attitude towards using AR application positively influences consumers' desire to use the AR applications.
P6: Desire to use an AR application positively influences consumers' intention to use the AR applications.

5 Conclusion

Notably, existing research has not sufficiently answered what kind of emotions are being evoked in users' interaction with the AR technology. Data collected from the focus groups strongly suggest that emotions significantly play a role in technology acceptance. The consistency in the participants' responses based on their profiles suggests that these findings could be tested further through an empirical study. By drawing on the themes as well as the propositions stated above, an empirical framework is proposed for testing in a subsequent study. It is hoped that the findings from this study could probably be generalised to other users in future study with empirical testing.

This exploratory study has few limitations. First, considering time and budget constraints, this study used a convenience sampling instead of interviewing customers from Sephora stores. Future studies can use real sample to test the findings. Besides, further studies should test the empirical framework by developing a questionnaire survey as follow-up research. By doing so, a complete understanding on felt emotions of consumers in using AR can be obtained. Finally, this study only focuses on few personal values and personality trait. Future studies should include other relevant variables to provide a more holistic view on user profiles of AR.

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Exploring How Augmented Reality and Virtual Reality Technologies Impact Business Model Innovation in Technology Companies in Germany

Richard Hagl and Aidan Duane

Abstract Newly-emerging, digitally-based technological innovations, such as augmented reality (AR) and virtual reality (VR), are new drivers for business model innovation. This study aims to develop a better understanding of the impact of AR/VR technologies on business model innovation in technology companies. The objective of the study is "to explore the impact of augmented reality and virtual reality technologies on business model innovation in technology companies in Germany". This paper investigates the body of knowledge regarding contemporary business model innovation and presents a conceptual framework to guide the research. The philosophical underpinnings of the study are discussed, and the chosen research methodology is justified. A holistic multiple-case study design targets German business-to-business technology companies employing AR/VR technologies to innovate their business models. The paper concludes with a discussion of initial learnings garnered from the implementation of a pre-pilot case study test run, and a full pilot case study.

Keywords Augmented reality · Virtual reality · Business models · Business model innovation · Case studies

1 Introduction

Digital technologies such as augmented reality (AR) and virtual reality (VR) are drivers for business model innovation (BMI) (Casadesus-Masanell & Ricart, 2011), and business models themselves may be shaped by technological innovations (Teece, 2006). This is especially true in the high velocity environment of the internet, where business models must be frequently altered to meet new challenges. These technologies are expected to offer significant revenue opportunities in numerous industries in the next few years (Ebert, von der Gracht, Lichtenau, & Reschke, 2017). However, new technologies—such as AR/VR—oftentimes have no obvious business case (Chesbrough, 2010), and little is known about their impact on BMI. Zott,

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Amit, and Massa (2011) note that "academic research on business models seems to lag behind practice" (p. 1022) and that "prior frameworks used in isolation cannot sufficiently address questions about total value creation" (p. 1029). However, "it is ill-understood how changing market, technology and regulation conditions generally drive revisions in business models" (De Reuver, Bouwman, & MacInnes, 2009, p. 1). Helping close this gap is a valuable contribution to theory, aligning it closer to practice. Thus, the objective is "*to explore the impact of augmented reality and virtual reality technologies on business model innovation in technology companies in Germany*".

2 Literature Review

Emerging technological innovations and business models are profoundly linked (Baden-Fuller & Haefliger, 2013), and BMI can be driven by emerging digital technologies such as AR/VR (Euchner, 2016). However, most entrepreneurs don't sufficiently understand what business models are, lack the skills to design appropriate models, and fail to innovate business models, as market conditions change. Hence, further research is needed. Our discussion starts with understanding AR/VR.

2.1 Augmented Reality and Virtual Reality: Business Model Innovation Drivers

A conservative prediction expects the market volume of AR/VR to jump from $3 billion in 2016, to $40 billion by 2020 (SuperData, 2017). Gartner (2016) placing AR/VR on their Top Ten strategic technology trends, conclude that "transparently immersive technologies identified within this theme are at, or over, the Peak of Inflated Expectations, … and they are now poised to achieve real productivity". These forecasts are founded on an assessment that AR/VR have reached sufficient technological readiness (Ebert et al., 2017), "offering more opportunity than ever before to create compelling AR/VR experiences" (Billinghurst, Clark, & Lee, 2015, p. 3). Key is widespread application of AR/VR across industries. AR/VR are broadly seen as potential new training systems for maintenance and assembly tasks (Gavish et al., 2015). Similarly, AR/VR promise to be beneficial for education purposes. Many of the world's largest companies have already incorporated AR/VR into marketing strategies: "innovative marketers can now leverage AR to craft immersive brand experiences, create more interactive advertising, and enable consumers to experience products and spaces in novel ways." (Scholz & Smith, 2016, p. 2). For destination marketing practitioners, theme parks are a potential market for AR (Jung, Chung, & Leue, 2015). Employing AR/VR for remote collaboration also offers novel opportunities: who can a user interact with (e.g. remote people), and how can be interacted

(Greenwald et al., 2017). Further promising fields are virtual showrooms and product configurators as pioneered by Audi and IKEA.

2.2 Business Models and Business Model Innovation

Companies may approach the commercialisation of new technologies, through the development of business models (Brettel, 2015). However, before entrepreneurs can go about innovating their business model, they need to comprehend what a business model actually is (Chesbrough, 2010). Business models can serve as communication tools (Morris, Schindehutte, & Allen, 2005), and "as a mediating construct between technology and economic value" (Chesbrough & Rosenbloom, 2002, p. 532). Business models can also be a source of competitive advantage (Lüdeke-Freund, 2013), as they are more difficult to imitate than product-, service-, or process-innovations (Schallmo, 2013). Ultimately, it may be that "a mediocre technology pursued within a great business model may be more valuable than a great technology exploited via a mediocre business model" (Chesbrough, 2010, p. 354). Business models are not static, but of dynamic nature (De Reuver et al., 2009), and companies striving for sustainability, need to continuously reinvent their business models (Sharma & Gutiérrez, 2010). Furthermore, BMI "can provide significant opportunities both during periods of rapid economic growth and at times of turmoil" (Giesen, Riddleberger, Christner, & Bell, 2010, p. 17). Furthermore, new digitally-based technological innovations coupled with innovative business models disrupt industry after industry (cf. Streibich, 2017).

However, BMI is challenging (Euchner, 2016), perhaps even more challenging than other innovation types, such as product, process, service, or management innovations (Schallmo, 2013). As a result, many BMI efforts fail (Christensen, Bartman, & Van Bever, 2016). On the one hand, these failures might be caused by the application of business model concepts which are too static (Euchner, 2016). On the other hand, even innovative, fully-functional business models may fail to produce economic return for the initiator, if they don't successfully fend off (more powerful) imitators (Casadesus-Masanell & Ricart, 2011). As suggested by "blue ocean strategy", "almost any business model will perform brilliantly if a company is lucky enough to be the only one in a market" (Casadesus-Masanell & Ricart, 2011, p. 4). Opposing, business models are likely to fail if surrounding market conditions and competitive settings are ignored.

More generally speaking, BMI refers to two different ideas: BMI in the sense of inventing or introducing entirely new business models (Christensen et al., 2016), or BMI in the context of innovating an existing business model. In the case of innovating an existing business model, the challenge arises that business models are generally designed to resist change (Christensen et al., 2016). This sends business models down a path of a potentially predictable business model life cycle or journey (Morris et al., 2015), thereby possibly failing to unlock the true potential benefits of active BMI. This is even more troubling, as continuous re-invention of an existing business is not optional these days, rather, failing to do so will debatably lead to business failure (Frary, 2017). Brettel (2015) suggests that BMI might be created through the reconfiguration of business model components and business model design types. However, innovating a business model is significantly more than the mere development of a novel service or product (Frankenberger et al., 2013).

However, neither business model development nor BMI have been exhaustively investigated. The continuous rise of information and communication technologies results in the need for ever increasingly complex business models (Osterwalder & Pigneur, 2004). Thus, not just technology, but business models for AR/VR must be innovative and continuously updated as well. This innovation-process however, needs to be managed, as a mal-fitting innovation-management-process may result in a lack of capturing value from innovation (Chesbrough, 2003). BMI is the next frontier for business model researchers, as it "represents a novel and more holistic form of organizational innovation" (Foss & Saebi, 2016, p. 201). Emerging technologies, such as AR/VR, trigger BMI (Casadesus-Masanell & Ricart, 2011), and BMI is an essential task when attempting to capture the benefits of technology driven transformation (Lambert & Davidson, 2013). Thus, BMI is defined as: *the continuous process of the creation of new business models or innovating any of the business model components or their interplay namely: value proposition, customer relations, value creation mechanism, value capture and finances; or innovating its business function capacity as a communication tool, mediator between strategic objectives and technology, and/or as a source of competitive advantage*.

2.3 Research Gap and Research Contribution

van Kleef, Noltes, and Van Der Spoel (2010) suggest there hasn't been a commercial breakthrough for AR. This perception changed somewhat as Pokemon GO resulted in surging Nintendo stock value. However, Zott et al. (2011) conclude firms need to do more than just forge technology onto products and services: if they wish to realise the commercial potential, they also need to design unique business models. Thus, digital technologies such as AR/VR are drivers for BMI (Casadesus-Masanell & Ricart, 2011), and business models themselves may be shaped by technological innovations (Teece, 2006). This is especially true in the high velocity environment of the internet, where business models must be frequently altered to meet new challenges. However, "it is ill-understood how changing market, technology and regulation conditions generally drive revisions in business models" (De Reuver et al., 2009, p. 1). This gap motivates the authors to establish how business models of technology companies are impacted by AR/VR as it will be a valuable contribution to praxis.

3 Research Methodology

The research objective is "to explore the impact of augmented reality and virtual reality technologies on business model innovation in technology companies in Germany". To guide the research effort, a conceptual framework was developed, and the following four research questions were formulated (Fig. 1):

RQ1: What types of AR/VR technologies are technology companies in Germany adopting?
RQ2: How are AR/VR technologies being applied by technology companies in Germany?
RQ3: How do AR/VR technologies impact BMI in technology companies in Germany?
RQ4: How can German technology companies maximise the benefits of AR/VR technologies for BMI?

3.1 Philosophy

Saunders (2011) identifies three main angles to approach scientific research philosophy; namely ontology, epistemology, and axiology. Depending on the researcher's ontological position, two main knowledge-creating epistemological approaches may be taken: a positivistic or interpretivist approach. A strict positivist does not consider studying social phenomena a worthwhile effort (Bhattacherjee, 2012), while strict interpretivists see no point in solely categorising phenomena in cause and effect (Holden & Lynch, 2004). Axiology is concerned with the roles of the researchers'

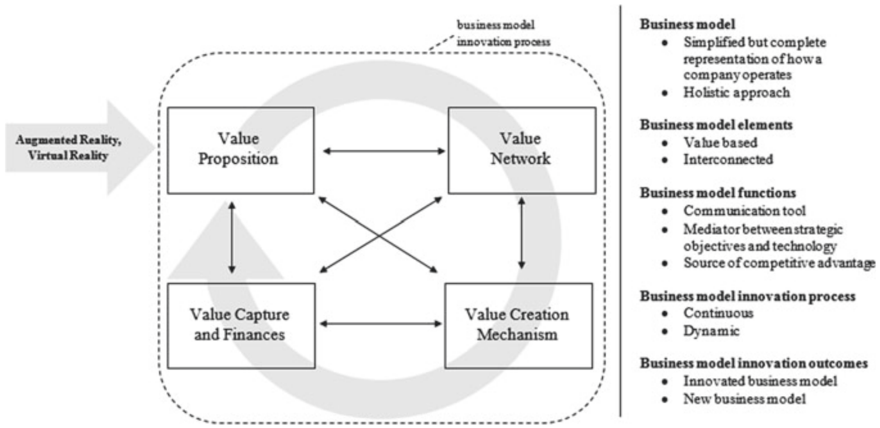

Fig. 1 Conceptual framework (adapted from Chesbrough & Rosenbloom, 2002; Morris et al., 2005; Al-Debei & Avison, 2010; Lüdeke-Freund, 2013)

values regarding research choices (Saunders, 2011). Consequently, a researcher's philosophical approach reveals some of the researcher's values and beliefs (Saunders, 2011). With reference to the two dimensions proposed by Burrell and Morgan (1979), "radical change" and "regulation", the authors hold a view of society of radical change. Furthermore, the 21st century is a time in which the pace of change accelerates, driven by technological innovations, and an ever more interconnected world. From an ontological perspective, the social world is to a large extent constructed in our minds, by observing phenomena and then attaching interpretations and meanings to them (phenomenological). Entrepreneurial opportunities can be created, rather than discovered, and whether a technological innovation finds extensive employment or not, ultimately is a choice made by humans. This in turn, is primarily influenced by the perceived importance that social actors give to the new technology and associated phenomena. This conviction places the author in the ontological camp of subjectivism. Oftentimes, and contrary to personal beliefs, technologically-driven changes unfold slower and are much less revolutionary. Similarly in this study, slower than expected growth is occurring in the AR/VR industry (Bastian, 2017), and these "order-preserving-forces" perhaps indicate, that taking a regulatory view of society is a useful approach for the study. However, some reports suggest AR/VR has momentum and a market upturn is possible (Ebert et al., 2017) though the pace of change is unclear. Therefore, it's imperative to understand what is going on in practice as a practical and insightful first step (RQs 1 and 2), before understanding how AR/VR impacts BMI (RQ3) or proposing changes (RQ4). This aligns with the interpretive paradigm rather than the radical humanist paradigm (Saunders, 2011). Therefore, an interpretivist paradigm is adopted. In summary, the study adopts a phenomenological, subjectivist, interpretivist philosophy.

3.2 Methodology

Saunders (2011, p. 4) uses "methodology" to refer to the theory of how research should be undertaken, and "methods" to refer to techniques used to obtain and analyse data. Thus, having identified an interpretivist philosophical stance, from a methodology perspective, "it tends to be *nominalist, anti-positivist, voluntarist and ideographic*" (Burrell & Morgan, 1979, p. 28). The nominalist approach aims to obtain phenomenological insights, rather than attempting to build on positivistic science (Holden & Lynch, 2004). Anti-positivism, employing qualitative methods, is a synonymous expression for the epistemological stance of interpretivism (Bhattacherjee, 2012). Voluntarism postulates that humans can act independently and by freewill. The ideographic approach opposes the nomothetic approach and aims at highlighting the individual's interpretation of a phenomena, rather than striving to deduct law-like statements about social life (Burrell & Morgan, 1979) by utilising quantitative methods. Consequently, the author contends, that a *qualitative research methodology* is well suited for the research objective.

Case study research is suitable to investigate a contemporary phenomenon in its natural context and to answer "how" or "why" questions (Yin, 2017). This study aims to explore the contemporary phenomenon of AR/VR and primarily strives to answer "how" questions. Therefore, this study adopts a *case study approach*. Defining and bounding the case is important (Yin, 2017), so the researcher understands the chosen unit of analysis as it shapes the types of data, as well as the data collection approach (Bhattacherjee, 2012). Thus, the authors identify AR/VR application deployments as the unit of analysis, to understand what impact this deployment has on BMI in technology companies. Examples of cases could be the deployment of AR/VR to innovate the marketing or training process in a company, or indeed, the creation of an entirely new firm. Thus, the study adopts a phenomenologist, subjectivist, interpretivist approach using holistic "Type 3" multiple case design (Yin, 2017, p. 48).

Creswell (2002) categorises qualitative data collection methods as observations; interviews; documents; and, audio-visual (AV) materials. The study notes all observations as field notes. Semi-structured interviews with key players in each case is the primary source of data. Data collected through observations or interviews is commonly done by preparing data collection protocols (Creswell, 2002). An interview guide and case protocol has been designed around the four research questions, and the conceptual framework also guides interview questions. The researchers primarily examine web-based documentation, consisting of case descriptions, marketing and company background information, but will consider other relevant documentation that may emerge. AV materials are treated analogous to documents. To manage data collection, the researchers developed a BMI case study database folder, a case study log, a case study mind map, and installed Redmine Project Management System.

4 Initial Findings

The author developed six criteria for pre-selecting cases: significant involvement in AR/VR; case completeness; case relevance for BMI; case general applicability; access; and relevant to Germany. An online search to identify cases applied 34 key phrases arising from literature, which when combined with the terms AR/VR, resulted in 68 English and 66 German search strings. The search took several days, resulting in 230 pages of data. Negotiating case access is time-consuming, however, interest in the research is significant due to its contemporary nature, opening doors in such innovative start-ups, as the pilot (Company #770001) and one of the largest German automotive consulting firms (#770005).

A pre-pilot test was conducted in April 2018 with a senior AR/VR developer. The interviewee chose a VR case rolled out to a client in 2017. The project created an innovative experience for exposition visitors. The project was accompanied by printed marketing materials and coordinated activities prior to/after the exposition. The pre-pilot resulted in minor changes to interview questions and ordering. The main benefit of the pre-pilot was psychological: the novice researcher's confidence increased significantly.

The pilot case, focused on expert interviews to test and refine data collection, commenced in May 2018. In this instance, “the case” is the company itself, a Berlin-based start-up, established in 2017. Company A is seed-funded by an investment firm holding a majority share and focuses on emerging digital markets. Company A has developed innovative VR for industry collaboration but spotting the opportunities to use AR/VR to innovate its own business model, has now morphed from a product-orientated start-up into an AR/VR software as a service agency. Interviews were conducted on site with the CEO and CTO. Reflecting on the research objective and research questions, the pilot case study reveals the following. RQ1: Core technologies used by German organisations identified by interviewees include Microsoft HoloLens, Oculus Rift, ODB, Photon, Unity, Vuforia, and surprisingly, standard off-the-shelf PC gaming hardware. RQ2: AR/VR are primarily used for digital assistance, to change business processes, or to support new business models. One VR collaboration product enabled instant design review, eliminating travel needs. RQ3: It became very evident that AR/VR enables significant business process transformation for clients of Company A, enabling instant feedback from stakeholders, faster decision making, drastically reduces errors (see it before you build it), results in huge cost savings, and faster development cycles. RQ4: Initial evidence suggests organisations should (i) focus initially on projects, gaining experience with AR/VR, (ii) build a framework with re-usable elements, (iii) develop in-house, outsource non-core business (iv) run very short development cycles. Furthermore, some surprises surfaced (i) slow market development, (ii) unexpected value proposition: for some clients “innovativeness in itself” provides value (iii) a clear discrepancy between business model importance and business model competence, (iv) AR/VR requires a lot of explanation for clients.

5 Conclusions

The results of the pilot case and the initiation (early stages) of additional cases, lends itself to re-open the discussion on what VR/AR really is. Definitions of VR/AR are very technology-, and human-experience focussed. From a BMI perspective, it might be wise to rethink these definitions. A refined understanding of AR/VR from BMI perspectives may also emerge as an important finding from this study. When it comes to AR/VR, it seems like numerous businesses are betting on “technologically-less-ambitious” business models. Real estate agent (#770010A) states it is now common practice in the real estate industry to present 360° photographs of properties, which are for sale. These 360° photographs are not presented via a virtual reality headset; rather, numerous images are combined and linked together. The result is a virtual tour which can be taken in a web browser. From a technological viewpoint, creating 360° virtual tours in a web browser, is much less sophisticated than developing a fully-immersive virtual reality experience. A company thriving well on a “low-hanging-fruit approach” when deploying AR technology is INDE, who uses interactive, large-scale AR installations to “inspire, entertain, inform and educate”. These business examples are less focused on leading-edge technology; and seem to be primarily centred on an innovative approach to business modelling, thereby potentially underlining the observation previously made by O'Riordan, O'Reilly, Duane, and Andreev (2014, p. 2), that "legendary firms that shape their industry structures are in fact business-model innovators"; rather than technology leaders.

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Implementation of Augmented Reality in Manufacturing: A Case Study Exercise

Katrin E. Brunner, Christine Perey, Philipp A. Rauschnabel and Mark Sage

Abstract Many companies are facing challenges implementing AR in various disciplines, including manufacturing. Against this background, there is a high demand to learn about major obstacles that come up during the implementation of AR in manufacturing, and to discuss strategies how to overcome those barriers. This current case study exercise resulted from an AREA-funded research project in collaboration with the xreality lab at the Bundeswehr University Munich. It presents a realistic situation of a fictitious yachting company that is confronted with multiple obstacles that come up with the implementation of AR in manufacturing. Trainers and educators can apply this case study. Participants of the case study should understand the challenges of implementing AR and discuss ideas of how to deal with these situations in real-life. Multiple approaches can be used to find answers to the proposed questions, such as (1) group discussions, (2) research in academic and industry publications (such as thearea.org blog), and/or (3) interviews or discussions with experts.

Keywords Augmented Reality · Manufacturing · Obstacles · Case study · Exercise · Training · Education

1 Augmented Reality: Revolution in Manufacturing?

Immersive technology and Mixed, Virtual and Augmented Reality are all terms that have analysts and industry visionaries excited, predicting that billions will be spent in the coming years. Virtual and Augmented Reality alone are forecast by IDC to grow to $162 billion in revenue by 2020. Especially Augmented Reality (AR)

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has the potential to become a disruptive technology in multiple disciplines such as marketing, education, innovation management, medicine, human resources, logistics, and manufacturing.

While the use for AR is wide-ranging, AR is generally defined as the enhancement of the real world by overlaying and realistically integrating computer-generated, virtual content into the environment (Jung, Chung, & Leue, 2015). A popular example of AR for the mass market is the 'Pokémon Go' app, which allows users to catch virtual creatures located in the real world (Rauschnabel, Rossmann, & tom Dieck, 2017). AR is typically considered as a medium that can be used on different devices, ranging from stationary over mobile devices (e.g. smartphones or tablets) to innovative AR specific wearables (e.g. smart glasses or smart contact lenses). In the near future, AR smart glasses are probably the breakthrough technology since they can be used hands-free (Rauschnabel, 2018).

For companies, AR can provide value in three ways (for a discussion, see Ro, Brem, & Rauschnabel, 2018): First, by developing new business models, where companies are entirely based on AR technology (e.g., Smink, Frowijn, van Reijmersdal, van Noort, & Neijens, 2019; Hilken et al., 2018). Second, by applying AR to reach customers, a concept termed "Augmented Reality Marketing" (Rauschnabel, Felix, & Hinsch, 2019). Third, by applying AR to execute existing tasks more effectively and/or more efficiently. One sector where actual performance, efficiency and bottom-line improvements are already being made is Enterprise Augmented Reality. Especially manufacturing is an emerging area of AR applications. Due to its complex internal processes and increasing globalization of supply chains, manufacturing companies need to access and exchange real-time information at different stages of the product lifecycle, i.e., design, prototyping, production, assembly, maintenance, and repair. Thus, AR technology is highly relevant in manufacturing by enabling users to simulate, assist and improve processes before they are actually carried out (Ong, Yuan, & Nee, 2008) and researchers argue that mobile AR applications will revolutionize the manufacturing industry in the future (Carmigniani et al., 2011).

While we observe an increased diffusion of AR solutions in manufacturing today due to enhanced AR software provision and the widespread use of hardware devices that are able to support AR applications (i.e. mainly smartphones and tablets), firms still face substantial challenges regarding a successful implementation of this innovative technology (Bottani & Vignali, 2019). Following prior research (Hein & Rauschnabel, 2016), we argue that the acceptance of AR technologies in manufacturing is relevant on two levels: On a corporate level, i.e. where top managers make and justify the decision to implement AR technology, typically based on strategic, legal and financial criteria. The second level is the user-level, where workers need to accept, adopt, and use AR technology. This is a particularly crucial level since the correct and intrinsically-driven use of AR is a crucial success factor to AR-efficiency.

The following case study has been developed as part of a collaborative research project between the Augmented Reality for Enterprise Alliance (AREA; thearea.org) and Universität der Bundeswehr München. It describes challenges of DreamerBoats Inc., a fictitious yachting company that is in the process of implementing AR in their manufacturing. Readers are encouraged to discuss ideas and strategies of how DreamerBoats can overcome these challenges.

2 Case Company: DreamerBoats Inc.

DreamerBoats is a world-leading company in the yacht business. Its position and long heritage are a great source of pride, but they are even more proud of their people. Every member of the expert team is committed to providing their clients with the highest quality products and services in a highly transparent and reliable fashion. Members of DreamerBoats' 150-strong team are enthusiastic, empowered by deep knowledge and inspired to think innovatively in order to achieve consistent excellence. Supported by a range of effective IT solutions, they bring unquestionable trust to the experience of owning, chartering, selling, crewing and building a yacht. In the yacht building process, DreamerBoats guides its clients through every stage of the building process. The company also provides clear and transparent reporting on a regular basis so that clients are kept informed every step of the way. During the planning stage the project manager works closely with the client to ensure that all of the requirements are carefully set out and budgets and timelines are realistic. Based upon the requirements and using in-depth knowledge of bidding processes and construction methods, three dimensional drawings are developed in a CAD program. During the construction process, DreamerBoats combines standardized processes with many customized elements in order to fulfil each client's individual desires and remain in budget and on time. The project manager pays regular visits to the yard throughout the building and outfitting of the yacht. Sea trials verify that the yacht is operating properly. Any issues are quickly identified and resolved. After the delivery, DreamerBoats remains on hand to manage all warranty items with the shipyard.

Since building a yacht is an extremely complex business, involving many parties and a substantial investment in order to deliver the highly individualized product, the team at DreamerBoats is always looking for innovative technologies that support their work. A small innovation team leads the introduction of Augmented Reality (AR) technology into DreamerBoats' production processes. Using wearable AR devices, the team studied the use of AR in the four phases of yacht building.

3 Use Cases and KPIs for AR in Yacht Building

3.1 Preparatory Work

Using AR-assisted visualization of models permits early and low-cost "virtual build" reviews during the design cycle. Engineers, designers, quality control professionals and clients are able to assemble, test and diagnose the construction plan prior to fabrication. Moreover, the manufacturer can digitally introduce the future yacht into the shipyard in order to review clearances for materials and tradespeople.

3.2 Work Instructions

Workers wearing AR displays will receive accurate and real-time work instructions in context with the tasks they are performing. If and when necessary, they will be able to receive assistance from a remote expert. If there are any changes to the standard operating procedures, these will be rapidly and centrally updated via technical publication systems.

3.3 Customization/Sign Off

During the assembly process, there may be decision points inserted at which time the craftsperson is able to offer customized variations. Examination of the progress with the client can be performed on site or remotely, and with contracting authority thus reducing delays when working on highly customized parts.

3.4 Intermediate and Finale Inspection/Documentation

At any time during the build and upon completion of any phase, work can be reviewed and documented easily, and exceptions can be logged and stored with the specification sheet in the digital work management system.

After testing and definition of use cases, the team seeks to establish and target the following key performance indicators (KPIs):

- project and product cost savings, while increasing flexibility;
- lower costs arising from rework and delays due to errors;
- lower time and skill levels required to complete all necessary steps.

In addition, complete project documentation is greatly facilitated as a result of accurate information being automatically stored in digital formats during inspection. However, feedback from managers during testing revealed multiple obstacles which need to be overcome in order to successfully introduce AR.

4 Common AR Obstacles in Manufacturing

The most common problems raised during interviews at DreamerBoat Inc. with manufacturing experts are described in the next sections.

4.1 Expectations of Business Line Managers and Corporate Executives

Business line managers and corporate executives at DreamerBoats are generally cautious about the introduction of new technologies due to uncertainty and costs as well as delays that emerged from past, insufficiently mature technologies. Hurdles that came up during the testing phase have reinforced their lack of confidence in AR-assisted tools. They deem AR to be easily overpromised and flashy. They are not convinced that AR addresses their needs or meets their requirements. Furthermore, DreamerBoats' managers place high value in their company's current working style and delivery of high quality, customized products. Changes in the production process are generally hard to push through. The fact that competitors do not use AR enhances the opinion that there is no need for AR adoption at DreamerBoats either. Thus, the challenge is to demonstrate and convince the line managers and corporate executives that the benefits of AR outweigh the risks.

Strategies to overcome this barrier:

4.2 Upgrading or Investing in Modifications of Existing IT Infrastructure

The IT Infrastructure is continually evolving at DreamerBoats. Although Internet connectivity is usually provided, it is still an issue for AR because the network latency is high and the quality varies throughout the plant, depending on the worker's position. Also compatibility with existing technical documentation, workflow management and security systems is problematic. Some of the systems that could be integrated with AR are offline (e.g., production plans are stilled transferred via USB sticks between laptops). The challenge is to introduce AR while continually upgrading existing infrastructure to enable reliable and rapid digital delivery of information within the factory. Once delivered to the worker's display, precise positioning of virtual information in relation to real world objects remains an unsolved challenge.

Strategies to overcome this barrier:

4.3 Resources, Budget, ROI, and Scalability

Software and hardware for AR is still very expensive and the CEO of DreamerBoats is not willing to invest as much in software and hardware that are still rapidly evolving. Also, for a variety of reasons, the use of AR is not applicable to all projects and processes. The management team wants to see scalable projects in order to invest fully in AR. Moreover, it is difficult to find IT staff that is specialized in the design of new digital processes and content for AR technology. Therefore, DreamerBoats staff in many roles across multiple departments must increase their understanding of AR strengths and limitations and invest in the new tools and people to make AR effective and scalable.

Strategies to overcome this barrier:

4.4 Legal (Workers' Rights)

Since workers in spaces where AR is being used may be or are filmed and recorded during the performance of their tasks, individual privacy issues arise. Workers complain about being controlled and surveilled (watched by "big brother"). They express feelings of anxiety and lack of trust or respect by the company. In addition, those who are not employed by the company, such as suppliers and clients, who need access and interact with workers onsite may object to having their likeness and movements captured or tracked by workers wearing AR smart glasses.

Strategies to overcome this barrier:

4.5 Health and Safety Issues to the Workers

Worker health and safety issues arose during DreamerBoats' pilot testing phase. One of the workers was too focused on the digital content on the screen and lost track of the real world and his surroundings. When disoriented, the worker's head encountered a ship propeller. Another employee fell down a flight of stairs due to not seeing the stairs while focusing on the field of view containing introductory or calibration content and moving backwards to complete the tasks. Other employees may complain of headaches, eye strain and dizziness while working and wearing smart glasses for extended periods of time. Those health-related issues are a big hurdle to the adoption of AR and urgently need to be solved.

Strategies to overcome this barrier:

4.6 Lack of Acceptance

Currently, one of the biggest issues facing AR adoption is workers' lack of confidence and acceptance. They do not experience benefits from AR use immediately or consistently. After initially being curious about the use of AR, they become resistant. Workers at DreamerBoats have become frustrated when working with AR and their willingness to use the devices on a regular basis has declined. When asked to explain their reluctance and resistance, no clear statements are given to the plant managers. Workers simply state that this new technology doesn't work, interferes with their methods, is not necessary or does not bring the proposed benefits to their performance.

Discuss:
What could potential barriers (i.e., reasons why workers are against AR) be?

What could potential benefits (i.e. reasons why workers are for AR) be?

How could DreamerBoats reduce the (perceived) barriers and strengthen the perceived benefits?

5 Tasks and Background

Your task is to consult DreamerBoats during the implementation process. For each section, you find a blank box for your suggestions. Please discuss how DreamerBoats should deal with each situation. If necessary, make assumptions.

5.1 Resources

To find answers to these questions, some background research might be useful. Leading blogs and magazines can provide insights into successful case studies, and academic research might give you a better understanding of how certain things happen and interrelate. The recommendations listed below are not complete and newer resources might come up. Therefore, consider them as a starting point only.

Industry Resources

- AREA Blog (thearea.org) provides resources related to AR topics in enterprise settings. Some materials are exclusively available for members but others are public.
- The Thomas Blog provides information on different topics relevant for the industrial marketplace, amongst others articles on AR in manufacturing (https://blog.thomasnet.com/augmented-reality-manufacturing).

Academic Studies

- Research on AR, privacy concerns and other risk factors can be found in Rauschnabel, He, and Ro (2018).
- A summary of acceptance research for AR can be found in Chuah (in press).
- Alcácer and Cruz-Machado (2019) review and discuss different tools for manufacturing 4.0 tools.
- Bottani and Vignali (2019) analyse and review the scientific literature relating to the application of AR technology in the manufacturing industry.
- Jetter, Eimecke, and Rese (2018) focus on the key performance indicators (KPIs) that are able to benchmark the impact of using ready-for-market AR tools on automotive maintenance performance.

5.2 About this Research

In 2018, the AREA has launched a new project, defined and voted for by the AREA members, targeting barriers to AR adoption in manufacturing. While many manufacturers have implemented AR trials for a while, proofs of concept, and tests, relatively few have rolled out fully industrialized solutions throughout their organizations. The goal of this AREA research project was to identify issues and possible strategies to overcome these barriers.

This is the first AREA research project that focuses on a single industry in which there are many use cases that can improve performance, productivity and safety, and reduce risks and downtime. The final project contains of both quantitative and qualitative components and the deliverables will include an AREA member-exclusive report and a framework for identification of common barriers and the best mitigation strategies.

This case study was based on interviews with 16 managers with different background from different industries. The interviews were conducted in 2018. A previous version of this case study had been published on the AREA website in 2019.

5.3 About the AREA

The AREA (thearea.org; Augmented Reality for Enterprise Alliance), led by Mark Sage, is the only global, membership-funded non-profit alliance dedicated to helping accelerate the adoption of Enterprise Augmented Reality by supporting the growth of a comprehensive ecosystem. From conversations with over 500 companies interested and investing in Enterprise AR, including enterprises who have implemented solutions, providers of AR technology, and non-commercial organizations, as well as the supporting case studies the AREA is collecting and sharing with the ecosystem, it is clear that companies deploying AR are gaining real, tangible benefits. Enterprise AR is solving or improving business problems including:

- Relevant data – presenting only the latest, contextual and useful information to workers, when they need it
- Better resource management – making experts available to the entire workforce
- Real-time compliance – capturing, recording and certifying processes for policy compliance
- Reduced time – improving the efficiency of infrequent and complex tasks
- Minimized errors – preventing human error and miscalculation
- Lower costs – lowering the impact of task interruption and errors.

Through the work of the AREA members, a few barriers to adoption have already been identified. These barriers include a combination of technology and business issues such as safety concerns, security issues, a lack of shared and agreed requirements for key use cases, and improvements to the User Experience when using AR. Moreover, more research and information into the questions business leaders have are needed before they are willing/able to invest in enterprise AR.

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Augmented Reality in Training Processes with VISCOPIC

Thomas Knauer-Arnold

Abstract It is an ongoing challenge for companies in all industries to train their employees. Augmented Reality (AR) is a promising approach to make such trainings more effective and more efficient. In this chapter, we provide insights into how AR can improve corporate trainings. Therefore, we present insights into the implementation of AR training tools at Deutsche Bahn (the largest German railway company) and the Audi Quality Management Centre (automotive). Both companies applied the VISCOPIC Pins solution on a Microsoft HoloLens Device.

Keywords Augmented reality · Manufacturing · Training · Education · Use case

1 Introduction

In a modern society that is undergoing rapid change, companies face major challenges. In order to remain efficient and economical, they must constantly adapt to change, modernize and find solutions—for all areas of the company. They are supported by advances in science, improved infrastructures, global networks and new technologies.

The question of knowledge transfer plays a decisive role in modernization in many companies. Teaching and learning in a professional context make a significant contribution to a company's success. This is particularly true for companies in which training requires a great deal of time and financial resources, or in which the training content has to take place on site or on machines during operation. Training in hazardous situations or a shortage of teaching staff also pose complex challenges for companies. Modern technology now offers an efficient and convincing solution, which also brings crucial advantages in the didactic-methodical area. Augmented Reality (AR) revolutionizes teaching and learning (Lee, 2012). Indeed, many industries have recently seen the potential of AR in training and education, such as medical (Barsom, Graafland, & Schijven, 2016), sports (Daiber, Kosmalla, & Krüger, 2013), or manufacturing (Webel et al., 2013).

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This chapter summarizes several advantages of AR in training and education. It will also discuss reasons why AR trainings were challenging to implement with standard software development practices. Following, VISCOPIC's software solution will be presented as a a simple tool to develop AR apps without programming skills. This is followed by case studies from leading companies that have implemented this AR solution. The chapter closes with a discussion on the future of training.

2 AR Technology and VISCOPIC Software Tools

2.1 AR in the Industry

Augmented Reality is a way to show information exactly when and where it is needed. With the help of Augmented Reality Smart Glasses (ARSGs) or existing AR enabling mobile devices (e.g., tablets or smartphones), content can be displayed in the real world and improve how users visualize information, receive and follow instructions, and interact with products to make work more efficient (Porter & Heppelmann, 2017).

There are many advantages that AR can offer in the training and education processes (Bacca, Baldiris, Fabregat, Graf, & Kinshuk, 2014). These include, but are not limited to:

- **Relevant information in real-time**: Data is always where it is needed, which allows an employee to act more efficiently (Rauschnabel, He, & Ro, 2018). Searching in conventional manuals, choosing the right information and taking the right data into consideration is often not efficient and leads to problems.
- **Hands-free**: With information displayed on data glasses, both hands are free to perform work steps while everything important is still visible for the user.
- **Realistic Scenarios**: Sometimes, trainings on complex machines have to be carried out. These can't be brought into the classroom to work on the object.
- **Visualization of complex and invisible information**: Often parts of machines aren't visible from the outside and not accessible. For both these problems in education, AR offers the solution. Training can be performed on realistic holographic twins of the machine.
- **Entertainment and Inspiration**: Often, workers are bored and not very motivated to take part in trainings. AR offers a hedonic "fun factor" (Rauschnabel, 2018) which can increase employees' intrinsic motivation to take part in such trainings. Research has also shown that AR can inspire users (Rauschnabel, Felix, & Hinsch, 2019), which means it motivates them to re-think their existing attitudes and believes. In a learning context, it motivates users to learn new things, a motivation that makes learning more effective.

2.2 Implementation Challenges and VISCOPIC Software Tools as a Solution

Despite the numerous advantages AR can offer to companies, the implementation of AR in companies is often very complex. As discussed by Hein and Rauschnabel (2016), two levels of acceptance are relevant in the context of AR: First, on a corporate level, companies need to be convinced about the benefits and costs AR can offer. On the one hand, these costs are purely monetary, since AR projects can easily be very expensive. On the other hand, these costs might also reflect internal conflicts, such as data security issues or the resistance of work councils. Second, employees need to accept AR in order to work successfully and ideally be enthusiastic about AR [for a review of acceptance factors, see Chuah (2018)].

In practice, the cost aspect was often a barrier to the implementation of AR in companies. More specifically, in order to implement a customized AR solution, many companies adopted solutions specifically developed for them. The development of individualized (i.e. non-standardized) tools is usually cost-expensive and time-consuming. This made, and still makes, AR unattractive to many companies.

This is where companies like VISCOPIC change the availability of technologies like Augmented and Virtual Reality or 3D. VISCOPIC develops solutions for AR and 3D data creation and management. The Munich start-up collaborates with companies like Audi, BMW, Volkswagen or DB Netz AG and is an official Microsoft Mixed Reality Partner. VISCOPIC's tools are an easy-to-use "drag and drop" solution where companies can adopt and customize various procedures to their needs. Similar to Wordpress for websites (instead of writing html code).

Customers' challenges and needs in individual projects let VISCOPIC identify recurring patterns, which were the impulse for the development of the software tools of the company. With these tools, users of all skill levels can create 3D and AR content themselves. Particularly important was the user-friendliness of the platform. The system should make it possible to everyone to generate extended reality contents, completely without programming knowledge.

The AR Software Tools by VISCOPIC resulting from this knowledge make Augmented Reality available also for laymen. No programming skills are needed anymore with the applications Pins, Steps and Polygons, which enable easy content creation and editing. These applications will be discussed in more detail hereafter.

2.2.1 VISCOPIC Pins

The PINS application (see Fig. 1) supports rapid prototyping of an AR app as well as the creation of scalable content. The application can be used to design Augmented Reality content for different end devices. The generated work and instruction steps can be projected onto real objects. In this way, work processes can be simplified in various areas by enriching objects and infrastructures with information.

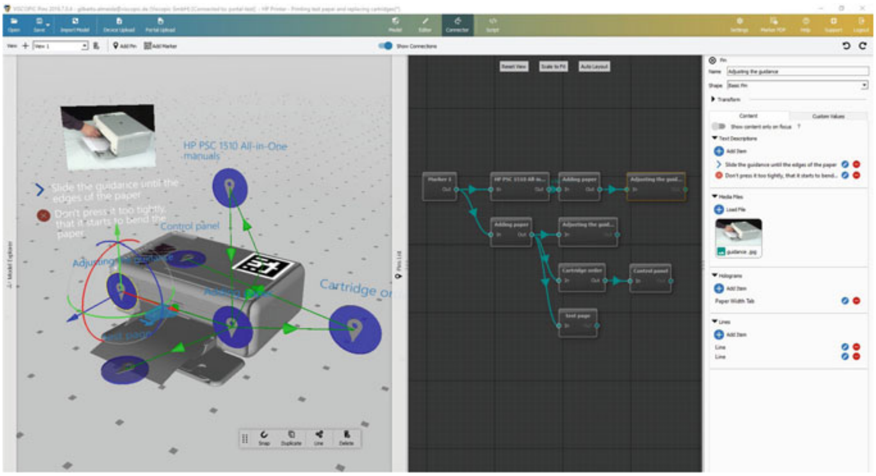

Fig. 1 VISCOPIC pins

The Windows application first generates a virtual 3D image of an environment or product, for example based on CAD models. Subsequently, different work steps and checklists—so-called Pins—can be attached to virtual objects. These can be enriched with information such as images, videos, sound, silhouettes or 3D animations. The work steps saved as a file can be opened via ARSGs, such as the Microsoft HoloLens, and on AR-enabled mobile devices like iPads or iPhones and projected onto the real environment.

If no CAD model of the object is available, workflows can also be created in the Pins Live Editor. The application for the HoloLens enables the user to place Pins onto the real machine by positioning holographic Pins and enriching them with pictures and media. The generated workflow can be saved and imported to the Pins Editor for further editing.

There are many use cases where such AR instructions can offer benefits. For example, they can enable the manufacturing industry to standardize its test procedures, help train employees and reduce the need for additional quality checks.

2.2.2 VISCOPIC Steps

Another VISCOPIC application, STEPS (see Fig. 2), offers the possibility to create interactive 3D training content or 3D animations from existing data and use them as work instructions or training content for employees in the same areas. The easy-to-understand Windows application ensures that processes of mechanical activities can be learned independent of time and place without a real system. In the Steps Editor, components of a CAD model can be provided with animations, which can show and display certain processes or correlations. The simulation of work steps is

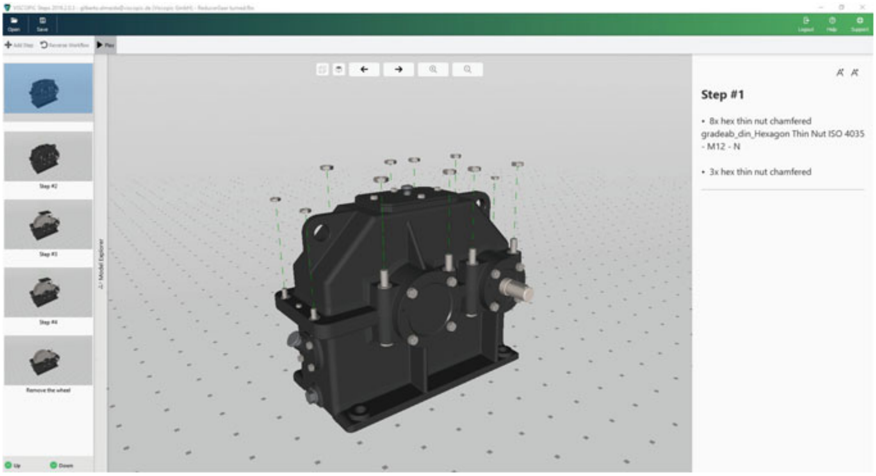

Fig. 2 VISCOPIC steps

very helpful as a work or training document. The disassembly of a robot can be easily learned with steps. Animations are assigned to components of the CAD model of the machine, for example a screw. In the simulation you can then see in which order which screws are dismantled and how. This makes even complex processes simple and understandable for everyone.

2.2.3 VISCOPIC Polygons

POLYGONS is a tool for optimizing 3D-models to enable displaying them on the HoloLens (Fig. 3). Since the computing power of many AR glasses is limited, it is difficult to stream larger models in real time to the smart glasses. However, this is necessary for some applications. VISCOPIC Polygons allows 3D models to be converted from CAD to mesh and to automatically remove invisible, irrelevant or very small parts. The software then allows you to stream large 3D models as holographic content via Wifi from a PC to the Microsoft HoloLens, without worrying about the limited processing power of data glasses. This can be especially helpful when planning production facilities or machine halls. Models of robots and machines can be projected into the room in real size as holograms in order to optimize the design of rooms such as production halls. The virtual images of the systems can be used to test where and how they should be placed. This avoids wrong decisions and facilitates the planning process enormously.

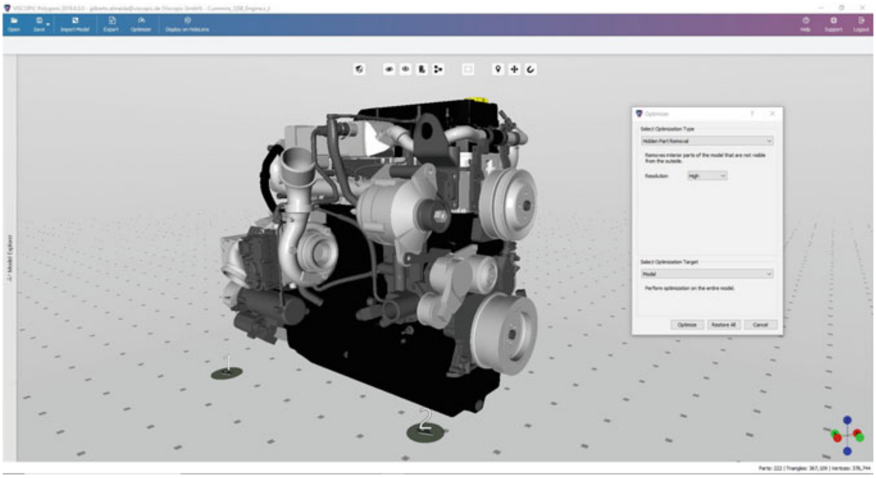

Fig. 3 VISCOPIC polygons

3 Importance of AR for the Training Sector

The reasons why AR and VR have such decisive advantages in learning and teaching lie in the fact that the working environment is very different. The following factors are central:

- In a real learning environment, the complexity is very high. Other objects and actions in the learner's environment can negatively influence and distract the learner. In the extended working environment, opened up by the new technology, a reduction is possible, i.e. unneeded, disturbing or irrelevant components can be hidden. The clarity is much higher.
- In conventional learning environments, influence on the dynamics of the environment is not possible. By marking or highlighting certain components, objects or processes when learning with AR, the environment dynamics can be influenced.
- Thanks to AR, the content of a training course can be better controlled and adapted faster than in a normal learning environment. Individual parts that would otherwise be installed in complex machines and would, therefore, not be visible and their functions can be displayed.
- In normal learning situations, expenditure of material, time and costs must be expected, which often makes training inefficient. AR trainings eliminate these disadvantages.
- When practicing complex situations, hazards can arise for the trainees, the instructors or third parties. Learning with holograms, on the other hand, is realistic and yet safe.
- In contrast to real learning situations, Augmented Reality training courses are available to everyone everywhere, at any time and from any location.

- Thanks to the new technology, learning can be made more flexible and individualised.

3.1 Optimal Learning for All Types of Learners with AR

In order to better understand the process of learning in different people, a distinction is made between three different types of learners: the visual, the auditory-communicative and the haptic-motoric type. Each of these types of learners are addressed through different ways of transmitting information and can better absorb and retain information through different media. The visual learner type mainly needs information in image, text or video form, which he can view and comprehend himself. Training that is purely about listening is nothing for this type of learner. However, for the auditory-communicative learner type, this typical school situation is more appealing, in which people can speak and communicate. The haptic-motoric learning type is often neglected, although many people have characteristics of this category. These people retain information best when they are connected with movements or, for example, when objects to be learned can be taken into their own hands and examined.

When looking at the different types of learners, it quickly becomes clear that all these very different types cannot be considered in conventional teaching and training. The usual form of training in seminars or lectures concentrates only on a small range of learning types, whereby a large part of the learners is not addressed and learns ineffectively or barely anything. But how can all participants of a training course who have different intelligences be addressed effectively and optimally so that the training is as efficient as possible and the knowledge is retained after the learning unit?

Augmented Reality offers the solution. All four types of learners can be covered by Augmented Reality. The visual learner type can learn better by displaying processes as animations, images or videos. The sound recordings and communication, which can take place via AR systems, are used specifically to address the auditory communicative learner type. The possible interaction with AR models is particularly advantageous for the haptic-motoric learning type. The displayed objects can be moved, navigated or turned around. The personnel can therefore be better prepared for new machines that are integrated into production. Learning content can be transferred quickly, efficiently and practically from any location without the need for any machine components.

3.2 AR in Theoretical Training

Augmented Reality has a very high potential to improve teaching and learning and to realize innovative learning scenarios. In the theoretical training processes can be shown, represented and explained in an interesting way by the use of AR, VR and MR. The most different types of learners can be addressed in class and thus optimally taught. The practice, which follows the theory, can be optimally prepared only by the previous theoretical learning of important procedures at a realistic illustration of the real situation.

3.3 AR in Practical Trainings

Augmented Reality is especially valuable in practical trainings. The problem with conventional trainings without Augmented Reality is that real exercise objects cannot be brought into the classroom. Up to now, specialist knowledge has been imparted through PowerPoint presentations and exercises on real points. This makes practical training in the necessary technical depth difficult and time-consuming. The latest technologies allow processes to be carried out directly on models and illustrations without the need for real components or materials. Even use cases, which in reality are rarely available for training, can be presented in Mixed Reality trainings. The following example shows the practical advantages of AR, VR and MR training.

4 Use Case Deutsche Bahn

Deutsche Bahn Netz AG (DB) has identified the need for a modernised knowledge transfer within the company and recognised the opportunities offered by technical progress. Together with VISCOPIC, the project "3D-Durchblick" (the German word "Durchblick" means 'perspective' and is also used to describe a situation where people have a solid understanding of something) was launched, which changes training and education within the company. The further training of employees as well as the induction of new colleagues is since then much easier, faster and more efficient—thanks to the use of AR.

In the past, training meant that several participants gathered in a classroom where a teacher gave information via screen presentations to convey the theory. Depending on the content of the training, this was later followed by a practical part, possibly involving greater logistical and material effort, smaller training groups, and extremely inflexible timing and location. This is how DB employees used to know training. The Company has switched to a modern training concept and, with the help of AR, is making teaching and learning engaging and very valuable for employees.

This ground-breaking technology has an almost unlimited potential for implementing innovative learning scenarios. By using AR, theoretical content can be interactively presented, adequately supplemented at the ideal time and explained in a multi-layered way. This makes it possible to do justice to different types of learners and to better reach them individually. Practical learning can first be practiced on a realistic representation. This makes it possible to establish a stronger practical relevance already in theory and to optimally prepare training courses in the real situation.

AR is particularly valuable in practical training and has clear advantages over classical methods. The problem with conventional trainings without Augmented Reality is that real training objects cannot be brought into the classroom. For this reason, DB has so far provided specialist knowledge through PowerPoint presentations and exercises at real switches. This makes practical training in the necessary technical depth difficult, place bound and time-consuming. New technologies enable processes to be outlined directly on virtual models and representations and subsequently, enlarged upon the real component. Also applications that are rarely available for training in reality can be presented in AR training courses.

AR applications also make on boarding processes considerably easier for new employees, i.e. colleagues learn how to operate a new machine without the help of an additional person. Usually this leads to an increased productivity, as capacities are not limited in the training. In addition, AR extends the scope for decentralized training and collaboration. Technical experts can be connected to the AR glasses via video chat and give the learner advice or explain backgrounds. In this case, the trainers have access to the learner's field of vision in order to instruct the learner, to select parts of the field of vision or to explain the context.

4.1 3D-Durchblick—The Leading Edge of DB

The above-mentioned advantages convinced DB to cooperate with VISCOPIC in the project 3D-Durchblick (see Fig. 4). Since then, AR has been used profitably at DB. How important AR has become in the area of training and how the quality of teaching increases, becomes clear in the concrete implementation:

The primary goal of 3D Durchblick is to increase the reliability of maintenance personnel—especially in the inspection and fault clearance of control and safety systems, such as point machines.

Using an AR application, maintenance technicians learn how to carry out complex processes that are necessary for their work. Hardly visible components can be shown clearly with AR data glasses and their function and maintenance can be understood. The recognition of defective parts or necessary repair steps and the control of results are easily taught and trained. With the help of AR, technicians can also be better prepared for rare events, as the additional costs for realistic simulation of those situations are comparatively low. Without the use of modern technology, vehicles would have to be taken out of service and made available for training purposes. This

Fig. 4 Durchblick

would result in train cancellations and thus high costs. The positive effect of this efficient training is that train delays can be avoided.

At DB, training content often revolves around complex components, such as switches, which in turn interact with other components that are often invisible from the outside. This demanding system with its dependencies and interrelationships is difficult to illustrate. AR can do more: no matter how large and complex a component is, it can be displayed comprehensibly with all components and decisive aspects. This way, correlations are presented logically and the didactic quality of teaching increases.

4.2 Three Apps with One Goal: Enhanced Learning and Teaching

AR is used to display animations and interactive tasks in trainings and learning, which can be used step-by-step to learn processes and test reactions. VISCOPIC supports DB with the development of three different applications for tablets and the Microsoft HoloLens.

App "Switch Inspection": In this application, the maintenance technician wears the AR data glasses HoloLens while moving on the real switch to check and maintain it. At the switch, the important inspection points are highlighted by virtual markings. The technician can already see from a distance where he has to check the switch. If he moves towards such a point, measurements and data that are relevant for the inspection are displayed. These remain in the inspector's field of view while he examines and maintains the switch.

App "Point Machine": In this application the hologram of a switch is projected into the room. The hologram can be used to display installed parts, name components and simulate processes. An additional function for tablets includes a quiz, which interrogates learning content.

App “RBC-cabinet”: The application makes it possible to learn processes at a Radio Block Centre cabinet (RBC cabinet) responsible for the safety of a moving train. As with the “Point Machine” app, components and operations can also be displayed here.

In all applications, a “trainer” and a “student” mode can be distinguished. In trainer mode, the teacher shares his field of view with the student. This means he can select and explain operations while the student sees the same holograms in identical perspective. This makes it clear to the student what the teacher is explaining and facilitates learning.

5 Use Case Audi

5.1 *The Change in the Automotive Industry*

The automotive industry is undergoing fundamental change—digitization, sustainability and electric mobility are the guiding principles of the future.

The German car manufacturer Audi is at the forefront when it comes to new technologies for use in quality assurance. The company focuses on new developments to meet tasks and requirements with a sustainable approach. In a joint project with VISCOPIC, Audi shows how valuable the use of Augmented Reality is in the automotive industry and which advantages it brings with it (see Figs. 5 and 6).

Fig. 5 Example of a training process with an Augmented Reality workflow at the audi quality management centre in Brussels

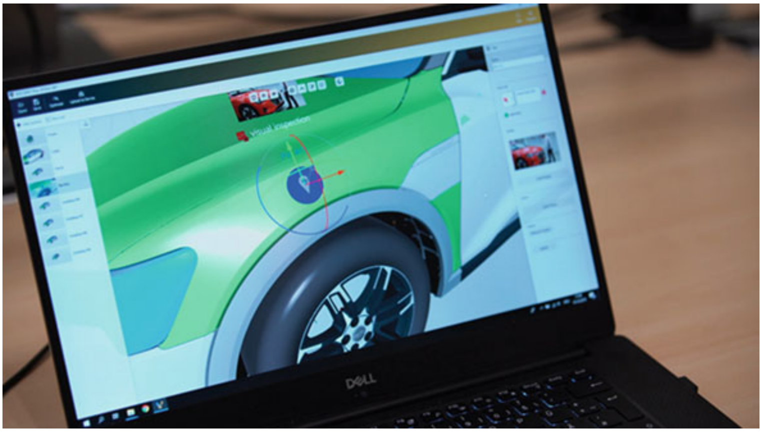

Fig. 6 Creation of an Augmented Reality workflow on a vehicle using the VISCOPIC Pins Editor

5.2 *Quality Assurance at Audi*

Many aspects have to be considered in quality assurance. Specifications such as dimensional information, the condition of components or distances must always be available and must be able to be checked in the shortest time possible. Not an easy task when there are only a few minutes for the quality control of a car and when the process is of utmost importance for the safety of a vehicle.

In order to keep all this data in mind for different vehicle types, a photographic memory would be required. Conventional paper documentation with the most important data proves to be rather complicated, while identifying and reading out specific data takes up a lot of time.

This is where Augmented Reality offers an approach that counteracts the above mentioned challenges and increases the efficiency of processes in quality assurance. Holograms, which can be seen on AR glasses, can be used to display important information on test steps and processes in the user's field of vision. In the application used by Audi, the components to be tested are marked and the respective test dimensions are displayed so that careful and accurate testing is conducted and no test steps are omitted.

The carmaker truly benefits from the use of Augmented Reality. The application standardizes all test processes and systematics in all plants worldwide and makes them easier to understand and control. Thanks to the training of test procedures in the Augmented World, new employees can also be trained quickly and productively.

How can an app like this be implemented? With the application VISCOPIC Pins, the creation of AR content is not only possible even for non-professionals without programming knowledge, it is also very easy and quick to use.

VISCOPIC Pins can be used to create Augmented Reality content for different end devices. The application supports rapid prototyping of an AR app as well as the creation of scalable content. The generated work and instruction steps can be projected onto real objects. Thus, work processes in different areas can be simplified by enriching objects and infrastructures with information.

In the Windows application, different work steps and checklists can be created through the so-called “pins”, as outlined in Sect. 2.2.1.

With the help of PINS, workflows for assuring the quality of a vehicle at Audi can be simplified by displaying important information as holograms in the right places on the car. Contents such as component markings, dimensional information or documentation videos are always and everywhere visible to the technician. At the Training Centres of Audi Quality Assurance, Augmented Reality is used for efficient and faultless training of new employees.

The learning phase can be greatly reduced, while the learning success is ensured. A further considerable advantage of the technology is the higher test quality and thus increased safety of the vehicles. With AR, work steps are carried out more accurately and important details don’t get forgotten or overlooked. The use of AR also creates an exciting experience for the employees, who can experience at first-hand how Audi is supported by digitization in production.

The test plan, which is visualized on the real vehicle via Microsoft HoloLens, can be created with just a few clicks and by drag and drop. This implementation by the Pins Editor is the key for a flexible use of the technology, which can be used regardless of the application, business area or location.

Audi and VISCOPIC have taken a step into the future together and set new standards through innovation in quality assurance. “Our goal is to simplify complexity with digital tools,” says Peter Mück, Head of Quality Assurance Innenmeisterbock. “Mixed Reality supports an interactive learning process without impairing the human senses. This facilitates the understanding of complex work processes and shows how digitization can support us.”

6 Summary and Outlook

Audi and DB were both looking for a solution to revolutionize training in their company and found a way through the Augmented Reality applications by VISCOPIC. The specialty about the use of the software PINS is the creation of scalable content that can be generated by personnel of every knowledge level.

The technologies around Augmented Reality are developing rapidly and are finding more and more fields of application, which results in a growing interest in the technology. The integration of AR has already led to significant progress in quality assurance at Audi and in training and education at Deutsche Bahn.

In the near future, more leading IT companies will launch new AR devices. Forecasts indicate that these devices will be smaller and more fashionable, have better computing power and so forth. Likewise, industry associations, IT security specialists, academics, and policy makers are working on rules and standards that reduce the risks of data security, measurement tools (e.g., Jetter, Eimecke, & Rese, 2018) and the privacy of workers and the people around them (Rauschnabel, He, & Ro, 2018). In short, the industry is getting ready for a new era of technology—a work environment that is consistently enriched with relevant virtual information. Even still in the early stage of this era, the examples discussed in this chapter provide initial evidence that AR can improve the effectiveness and efficiency of numerous processes.

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Virtual Reality Becoming Part of Our Lives—Assessing Consumers' Perceived Applicability of Virtual Reality Supported Tasks and a Critical Reflection on the Development

Marc Herz and Vanessa Rahe

Abstract With virtual reality technology rapidly advancing, virtual reality glasses can be used for a growing number of tasks and thus become increasingly integrated in consumers' lives. The present study reanalyzes an existing dataset from a quantitative study with 611 German consumers to assesses their perceived applicability of virtual reality glasses in various tasks. Further, this study identifies situations and explores the relationship of virtual reality tasks with attitudes and purchase intention of virtual reality glasses. Finally, the present paper offers a critical reflection on the increasing adoption of technology in our everyday lives from an ethical and sociological perspective and offers impulses for future research.

Keywords Virtual reality · Tasks · Critical reflection of technology

1 Introduction and Theoretical Background

Over the last decade, virtual reality (VR) has become more and more important in various professional and personal situations (Sachs, 2016). While industries and major companies increasingly integrate VR technologies in their supply chains and offers, and consumers' adoption rates on the rise, the overall VR market is expected to further grow substantially in the years to come (Herz & Rauschnabel, 2019; Rauschnabel, Felix, & Hinsch, 2019).

In general, VR can be defined as a type of digital, immersive media that generates a three-dimensional, virtual imaginary. The technology thereby creates an interactive environment in which individuals can act and interact in a similar way to a physical reality (Craig, Sherman, & Will, 2009; Slater, Spanlang, Sanchez-Vives, & Blanke, 2010). VR technology mostly comes with a wearable device, thus a device that is

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physically attached to a user's body, such as smart glasses, e.g. ARSGs like Google Glass, or VR glasses such as Oculus Rift (Chuah, 2019; Kalantari, 2017). As in the real world, VR technology allows users to engage in different tasks which can be both hedonic and functional in nature.

Often associated with hedonic activities, such as gaming or entertainment (Shelstad, Smith, & Chaparro, 2017), various forms of VR technologies are used for functional tasks, such as learning, trainings or communicating (Huang, Rauch, & Liaw, 2010), education (Freina & Ott, 2015), medicine (Hayhurst, 2018), or even in therapeutic applications (Cameirão, i Badia, Oller, & Verschure, 2010; Rendon, Lohman, Thorpe, Johnson, Medina, & Bradley, 2012). With the technology rapidly developing, there are more and more opportunities to include VR glasses in many diverse occasions of life and use VR glasses for various tasks. In short, the expected benefits are immense. However, it is important to note that the extant knowledge is mostly fragmented (i.e. assesses specific aspects of VR only) and highlights the positive aspects of VR. Systematic assessments and critical aspects on VR remain scarce. This is where this chapter contributes to. In particular, it is of interest to understand which tasks consumers would primarily use VR glasses for and how perceived applicability of these VR supported tasks correlates with consumers' perceptual and behavioral attitudes towards VR glasses.

The present study seeks to shed light into consumers' perceived applicability of VR supported tasks and their relationship to attitudinal perceptions and behavioral intentions (in our case purchase intentions) to answer the broad research questions:

(1) *For which tasks would consumers use VR glasses?*
(2) *What is the relationship between VR supported tasks and consumers' attitudes and behavioral intentions?*

In addition to the empirical assessment, the present paper takes a critical perspective on the progressing technology integration in our everyday lives. Specifically, the present reflection comment briefly touches ethical and sociological issues surrounding the increasing technology adaption in general—and VR technology in particular—in various tasks and aspects of consumers' lives.

2 Background and Research Gap

Moving from a niche topic to mainstream, there is an increasing number of studies focusing on VR. Most studies in the field solely highlight the general benefits of the increasing technological advancements for consumers (Han & Dieck, 2019; Han, Weber, Bastiaansen, Mitas, & Lub, 2019; Rauschnabel, 2018) and businesses (Rauschnabel, Felix, & Hinsch, 2019). Only few studies assess the actual application of VR glasses, look at consumers' negative perceptions of the technology or critically discuss the application of the technology in our everyday lives: Yang, Yu, Zo, and Choi (2016) analyze customers' perceived value and subsequent user acceptance of wearable devices. Herz and Rauschnabel (2019) explore what benefits and risks drive consumers' reactions to VR glasses and how VR supported factors affect user adoption of these devices. The authors thereby assess consumers' fears, hesitations and perceived risks (health, physical, psychological and privacy risks). Chuah (2019) conducted a comprehensive literature review of the XR (Cross Reality) literature and created an intense list of benefits and risks. Rauschnabel and Ro (2016), and later Rauschnabel, He, and Ro (2018) analyzed benefits and risks of AR (Augmented Reality) smart glasses. They found that consumers do not tend to incorporate threats to their own privacy into their decision making, but therefore tend to care about other people's privacy.

In the context of VR, various studies assessed negative short-term consequences, such as dizziness or motion sickness. Other discussed the idea of physical injuries or addiction.

The present paper conducts a critical reflection on technology becoming a substantial part of our everyday lives which can provide an impulse for future studies and more critical and reflective assessments of the topic. We thus provide three major contributions. From a *theoretical perspective*, we explore which tasks consumers would most likely use VR glasses for and assess the relationship between these tasks and consumers' attitudes as well as behavioral intentions. By doing so, the study provides profound insights into how consumers use or would use VR. These findings can stimulate future research and provide insights into unmet needs VR can satisfy. From a *managerial perspective*, we provide stakeholder in the VR sector with specific insights on consumers' perceived applicability of various VR supported tasks and thus impulses for future developments and communication strategies. This can be particularly interesting for brand managers, as VR applications may be a novel approach to actively build additional consumers' memories (cf. Herz & Brunk, 2017). From a *sociological perspective*, we provide researchers and policy makers with a critical discussion of the progressing technology adaption and impulses for more reflective future assessments and evaluations.

3 Methodology

We assessed consumers' perceived applicability of various VR supported tasks in an empirical approach using a quantitative survey method.

3.1 Data Collection and Sample

Using an online panel by a professional market-research firm, we surveyed 611 German consumers with different (socio-)demographic backgrounds. We used quotas on age, gender and area of residence (urban vs. rural) taken from official German statistics. 287 of the respondents were male (47%) and 324 females (53%). Age ranged from 18 to 84 years with an average age of 50.27 years (SD = 17.38). 47

respondents were students, 302 respondents were full-time or part-time employed, 24 were unemployed and 183 respondents were retired. Respondents received financial compensation for participation. We specifically included all consumers, whether they know/own VR technology or not, in order to establish a non-fragmented perspective on consumers' actual attitudes and behavior toward VR glasses. Notably, 13.3% of the respondents had never heard of VR glasses, 76% had heard of the technology (but never tried it), 8.7% had tried VR glasses and 1.4% own a device.

3.2 Measurement

Consumers perception of the applicability of 14 different VR supported tasks was measured. Using a 7-point Likert scale (from 1 'totally disagree' to 7 'fully agree'), we asked respondents whether they would consider using VR glasses for the tasks as applicable. The options included various hedonic and functional tasks, such as gaming, watching videos, exploring exhibitions, chatting with friends; as well as tasks such as learning or completing everyday duties. We further added various commercial VR supported tasks, such as interacting with brands, learning about companies, or buying products in virtual worlds.

In addition, we assessed consumers' perceptions and behavioral intentions towards VR glasses. Using a 7-point Likert scale (from 1 '*totally disagree*' to 7 '*fully agree*'), we assessed consumers' general attitude ['*My overall attitude towards VR glasses is very good*'; adopted from Davis (1989)], positive attitude ['*Generally, I have a positive attitude towards VR glasses*'; adopted from Davis (1989)] and purchase intentions ['*I would buy VR glasses*'; adopted from Lu, Hsu, and Hsu (2005)].

3.3 Results

In the first step, we assigned 14 VR supported tasks to five specific task areas: 'Entertainment', 'Escape reality', 'Tasks and learning', 'Social interaction' and 'Interact with companies and brands'. Figure 1 provides an overview of the mean values and of the items assigned to each category.

It shows that virtual reality most likely fulfills the task of 'Entertainment': Thus, the mean value for the sub-dimension 'watch 360° videos' is M = 4.44 (SD = 2.09), closely followed by 'virtually explore museums and exhibitions' (M = 4.37, SD = 2.05) and 'gaming' (M = 3.48, SD = 2.19). The second strongest are the dimensions of the group 'Escape reality': 'escaping everyday life' (M = 4.30, SD = 1.98) together with 'coming to other thoughts' (M = 4.27, SD = 1.92) is at the front, closely followed by 'diving into another world' (M = 3.77, SD = 1.95). The sub-group 'Tasks and learning' comes in third place, although the mean values are each of varying degrees of intensity: 'learning new things' (M = 4.06, SD = 1.89)

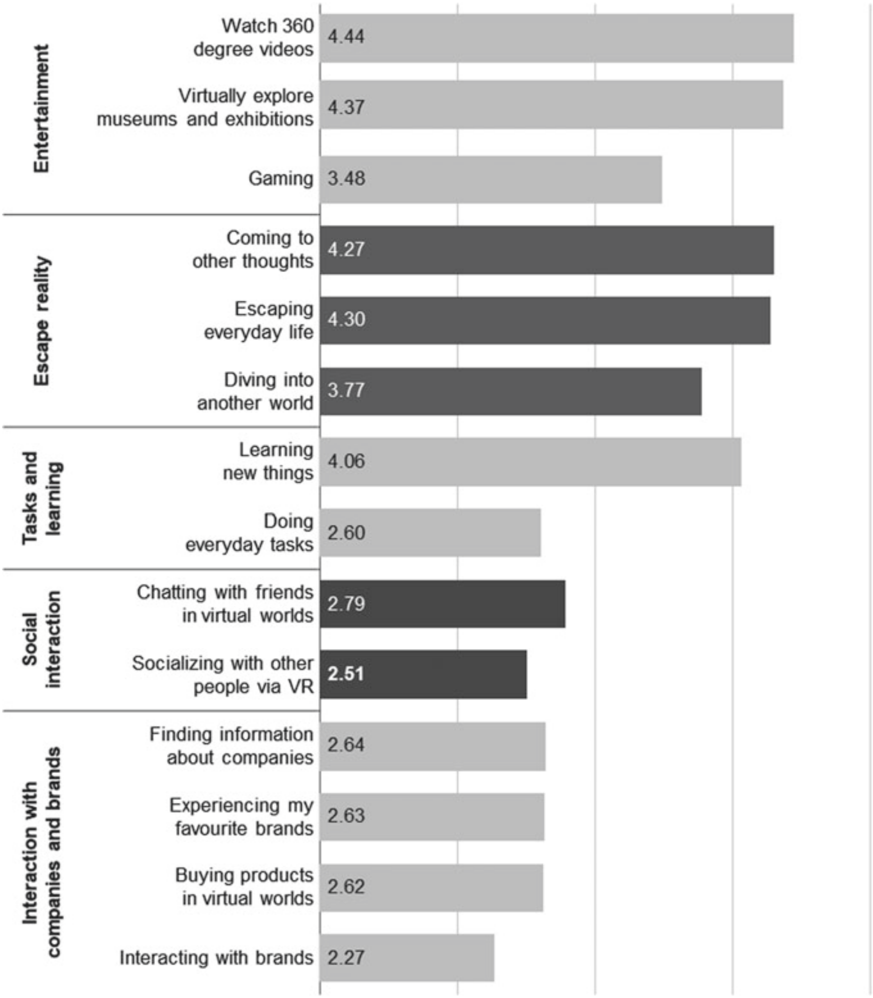

Fig. 1 Consumers' perceived applicability of VR supported tasks

gets almost two scale points more approval than 'doing everyday tasks' (M = 2.60, SD = 1.63). As the values for the category 'Social Interaction' show, socialization seems to be associated only subordinately with virtual reality: 'chatting with friends in virtual worlds' (M = 2.79, SD = 1.80) and 'socializing with other people via VR' (M = 2.51, SD = 1.65) are hardly accepted by the respondents. The commercial VR supported tasks 'interact with companies and brands' also have little relevance: 'finding information about companies' (M = 2.64, SD = 1.70) and 'experiencing my favorite brands' (M = 2.63, SD = 1.73) or 'buying products in virtual worlds' (M = 2.62, SD = 1.74) are categories hardly anyone wants. 'Interacting with brands' (M = 2.27, SD = 1.54) is an even weaker sub-dimension.

In the second step, we analyze how and whether the tasks which may be conducted with VR interact with consumers' perceptions and behavioral intentions. We assess how specific types of VR tasks correlate with attitude towards VR glasses, as well as purchase intention of VR glasses.

As Table 1 shows, all possible tasks of VR highly correlate ($p < 0.001$) with consumers' attitudes towards VR glasses. It is not surprising that 'Entertainment', as the dimension that has gained the most approval, also has the highest correlation with attitudes towards VR glasses, as well as purchase intentions of VR glasses. 'Escaping reality' shows the second highest correlation with attitudes and purchase intentions of VR glasses, followed by 'Tasks and learning', which show slightly lower correlations. Next, 'Social interactions' show lower, yet significant correlations with attitudes towards VR glasses, as well as purchase intentions of VR glasses. Finally, 'Interaction with companies and brands' shows the weakest, however significant correlations with attitudes and purchase intentions. Overall, these results show that VR tasks highly correlate with consumers' attitudes and behavioral intentions and thus appear to be a driving force for the adaption of the technology. In short, if consumers see VR glasses as being beneficial in certain tasks, this positively correlates with their attitudes and behavioral intentions.

4 Discussion and Conclusion

It is noticeable across all groups that none of the factors show saliently high values. Consumers rate the usability of VR glasses to fulfill tasks rather limited and restrained. Virtual reality is most likely to fulfill an entertainment function for the respondents in order to escape reality to a certain extent. Although the respondents are generally open to learning something new with virtual reality, they tend not to want to do everyday tasks with it. The integration of virtual reality in everyday life may still seem to be met with considerably large skepticism, the everyday compatibility of VR glasses is still limited. While it is possible to arrange online meetings with friends and family via Skype, video chats or even games in order to overcome long geographical distances, socializing via VR still seems to play a secondary role. Finally, respondents do not appear to be particularly open to interactions with companies and brands. When asked directly, consumers state that using VR to experience a brand or get in touch with companies more closely plays a minor role. This may be because such interaction is still unfamiliar to a large majority of consumers, or consumers may interpret such an interaction as a 'commercial intrusion' of their private activities. In addition, they may associate it with an obtrusive penetration of calls for purchase, rather than with relevant and valuable marketing information (e.g., content marketing).

With tasks and consumer attitudes strongly correlating, our results show that when consumers regard certain VR supported tasks as applicable, they hold more positive attitudes towards VR glasses and are more likely to purchase VR glasses (cf. Herz & Rauschnabel, 2019). With task applicability being a salient factor in

Table 1 Correlation of VR tasks with attitudes and purchase intentions

	Entertainment	Escape reality	Tasks and learning	Social interaction	Interaction with companies and brands	General attitude	Positive attitude	Purch. intention
General attitude (My overall attitude towards VR glasses is very good)	0.615**	0.550**	0.512**	0.376**	0.296**	–		
Positive attitude (Generally, I have a positive attitude towards VR glasses)	0.645**	0.562**	0.536**	0.364**	0.326**	**0.899****	–	
Purchase intention (I would buy VR glasses)	0.572**	0.511**	0.432**	0.419**	0.396**	**0.754****	**0.745****	–

**Correlation is significant at the 0.01 level (2-tailed) consumers' decision making process, managers should focus on a convincing line of argumentation highlighting the use and applicability of the focal VR supported tasks (Han & Dieck, 2019).

5 Critical Reflection of (VR) Technology Use in Today's World

With the present findings at hand, two crucial questions come up: How many tasks should be supported and replaced by technology in the first place and therefore how dependent do we want to become from these technologies?

In the literature, most technology acceptance theories almost exclusively analyze the benefits of the technology of interest, widely neglecting the actual and perceived risks and consumer criticism (e.g., Herz & Rauschnabel, 2019; King & He, 2006; Venkatesh, Thong, & Xu, 2012). However, our study results provide the breeding ground for the critical questions that have just been posed: Consumers showed considerably limited enthusiasm to the adoption of VR glasses in various tasks, as many respondents appear to be rather skeptical. The participants in our study would most likely use VR for entertainment or escaping reality. Yet, the integration of VR glasses in our everyday life, our daily togetherness, virtual appointments and the exchange with our favorite brands is not (yet) seen as an essential part for most consumers.

When looking at adoption rates of new technologies and devices, there has not been a time in history when consumers were so quick in changing their attitudes and behavior towards technological and digital advancements. After all, digitization opens opportunities for efficiency-focused people that seemed unattainable for a long time. We do not even want to call these advantages into question. But we should keep in mind that work, leisure time, relationship, education and even sleep are measured, evaluated and permanently optimized. Without our smartphone, without tracking of our data and our digital connections, we feel more and more helpless in the face of efficiency expectations. Can we still switch off (our mobile devices or our brains) without a guilty conscience? Do we even dare to tell others that we are not reachable? Do we get nervous when the smartphone always rests on the bedside table? In this context, there is an established branch of communication research dealing with the phenomenon 'Permanently Online-Permanently Connected (POPC)' (cf. Vorderer, Hefner, Reinecke, & Klimmt, 2018). Our everyday life is digitalized and mediatized. So how humane is digitization? Who has the upper hand here? The people or just our data and codes? With smartphones being carried around with us, smart home devices being integrated in our houses, smart watches being physically attached to our bodies, VR glasses go one step further by not only being physical attached to our bodies, but blocking, adapting or changing certain senses. Over the last decades, human behavior has adapted itself to the technological developments and has become more and more functional. However, debauchery, inefficiency, boredom and long-suffering are not functional, but merely human. If we want to remain efficient and yet humane, we must renegotiate the boundary between humanity and technology. Are VR glasses the natural next step of technology becoming increasingly integrated into our bodies? Is optimization of every aspect of our lives the ultimate goal? How far would we go by letting technology being part of us and artificial intelligence making decisions for us? How can we remain human in this development?

Finding answers to all these big questions is probably not possible, but that is not our goal. Rather, we want to encourage reflection and encourage people to form their own opinions. In our daily work in our strategy consultancy Kleinundpläcking, we challenge ourselves, our clients and their business models with these questions and impulses. Only the continuous self-challenge of allegedly given facts and perspectives as well as an open discourse improve business models, customer satisfaction and ultimately people's lives.

As mentioned before, this discussion should thereby not accuse digitization and technological advancement, quite the contrary. It is an impulse stating that the human aspect is not lost in the digital revolution. We should become aware of how we want to live digitally in the future and how we do not. VR in particular not only offers tremendous opportunities, but also holds various risks, especially as it goes one step further in physically merging an individual with the technology and actively manipulating physical senses.

Within the last few years, there have been more and more calls for a critical discussion on the progressing technology adaption and particularly the increasing loss of control within this process. We need a holistic discussion on this controversy from an ethical as well as a sociological perspective held by researchers, policy makers as well as the general public to develop a framework to understand and control this process.

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AR and VR for City Planning, Smart Cities and Autonomous Vehicles

Mixed Reality Media-Enabled Public Participation in Urban Planning

A Literature Review

Mario Wolf, Heinrich Söbke and Florian Wehking

Abstract Public participation in urban planning processes is affected by what is known as the "paradox of participation": in early planning phases, when there is still sufficient room for decision-making, only a few citizens participate, while in late phases, when decisions can usually only be revised at great expense, a high level of public participation can be observed. The resulting delayed and more costly planning processes could be partially prevented by shifting public participation activities from late to early phases of planning processes. The reasons for the low level of participation of citizens in early planning phases are seen as the lack of clarity and the absence of concern due to a high level of abstraction. In this article, we examine the approach of using Mixed Reality (MR) media to remedy the paradox of participation in planning processes. Methodically, the context of MR media in urban planning is developed initially. Then the results of a literature study on MR media in urban planning are presented. Finally, the advantages of the use of MR media in urban planning contexts are summarized. In summary, MR media appear to be a promising approach for resolving the paradox of participation. However, future work should systematically structure MR media in urban planning according to characteristics supported, such as application contexts, planning objectives and modes of collaboration.

Keywords Mixed reality · Urban planning · Paradox of participation · Beteiligungsparadoxon · Visualization · Accessibility

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1 Introduction

1.1 Urban Planning

Urban planning is understood as the design and regulation of the spatial development in cities and rural areas (Schubert, 2015). Referring to the use of spaces, urban planning focuses on different dimensions shaping our cities such as physical forms, economic functions, social activities as well as natural aspects. The fields of application of urban planning are wide-ranging and cover a large set of subjects. Such as general design of urban districts, urban redevelopments and the protection of green and open spaces (BBR, 2000). Although districts, cities and regions are facing individual challenges, planners are increasingly sharing a common understanding of planning and its methodological approach. In detail, challenges as climate change, demographic shifts and economic transformations have led to the perception that the design of sustainable and resilient cities requires an integrated and cooperative planning approach. This refers not only to the coordination of different administrative bodies but also to the inclusion of the general public into planning processes (BMUB, 2007).

The basis of the involvement of the public are two sets of participatory instruments. On the one hand there are the so-called formal participatory instruments. This set comprises instruments being mandatory in planning processes. An example for a formal participatory instrument in Germany is that draft plans need to be laid out for public inspection. In the set of formal participatory instruments, not only the intensity and the timing of the participation is regulated, but also the groups of stakeholders, such as administrative bodies, public utility providers and certain groups of citizens having to be involved in the planning process (Lück & Nyga, 2018; Nanz & Fritsche, 2012). On the other hand, are the so-called informal participatory instruments. This term refers to instruments not being required by legislation but being optionally available to strengthen public participation in planning processes. Informal participatory instruments focus on conversational and deliberative approaches in opinion and decision making. For this purpose, the set offers a wide range of instruments, such as Open Space or Planning Cells (Nanz & Fritsche, 2012; Selle, 2013). In normative planning processes the formal instruments are supported by informal instruments to increase the level of satisfaction of all stakeholder groups involved in planning processes. However, the current participatory framework appears as not sufficient. A survey has revealed that more than 68% of citizens in Germany demand more opportunities to participate in the planning of infrastructures (Universität Leipzig, 2013).

1.2 Public Participation

Despite the shift towards a more inclusive planning, numerous projects of infrastructural planning evoked public resistance in the past years in Germany. The structural range is wide, from local projects such as the Waldschlösschenbrücke in Dresden (SPON, 2007) to trans-regional development projects like Stuttgart 21 (StN, 2018). From these examples it also emerges that the participatory instruments actually practiced in projects of infrastructure planning are of only minor interest, that only a small number of the actually known participatory planning instruments are applied and that the participatory planning instruments reach only a limited part of the stakeholder groups (Rösener, 2011). The German term "Beteiligungsparadoxon" (English: "paradox of participation") is related to this phenomenon. In the context of urban planning in Germany, the term has been coined by Reinert and Sinnig (1997) and has been continuously discussed in German planning practice and philosophy (HBS, 2014; Rehberg and Hoffmann, 2014; SenSW, 2012). The term describes the apparent conflict that usually the interest of citizens to actively participate in planning processes is generally low at its beginning. At the same time, at the beginning of planning processes, the options of influencing the planning processes are considerable high. However, during planning processes the engagement of citizens usually increases reaching its peak during the implementation phases. In contrast, the options of influencing the planning are decreasing in latter phases of planning processes. These dynamics lead to the conflict, that the greatest interest of citizens to participate in planning processes appears when most major decisions have been made and projects have reached their implementation phases leaving only little and costly options for adjustments to the plan (Fig. 1). It should be noted that the German term "Beteiligungsparadoxon" is well established in the sense described, while the English translation "paradox of participation" does not represent a fixed phenomenon. Paradox of participation is used in a broader sense for various phenomena, among others in political science

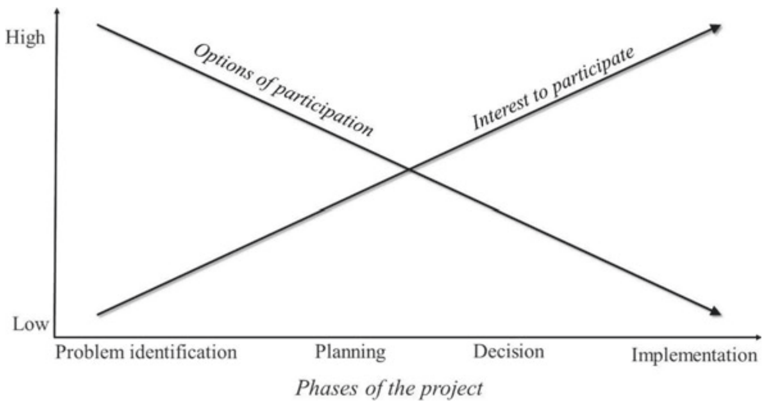

Fig. 1 Paradox of participation. Adapted from Reinert and Sinnig (1997)

(Cleaver, 1999; Strom, 1975). We use the term "paradox of participation" in the following in the sense of the German term "Beteiligungsparadoxon".

Explanations for the paradox of participation include a number of reasons, such as a long lapse of time between planning and the implementation of the project, confusing and complex administrative procedures, public trust in the planning goals (Hirschner, 2017), late participation of the public through formal instruments (Universität Leipzig, 2013), a high level of abstraction of plans and lacking individual and personal concerns of citizens at the beginning of the planning process (SenSW, 2012).

1.3 Technology-Based Planning Instruments

To address the challenge of the paradox of participation and prevent the formation of the planning conflict, inclusive participatory instruments are required. Hirschner (2017) states that participatory planning needs to be strengthened through the application of innovative informal instruments to achieve a higher identification and acceptance of all stakeholder groups. Informal planning instruments should focus on deliberative methods and the involvement of the public in early phases of the planning process. Instead of compromises, consensus needs to be generated based on persuasive arguments (Hirschner, 2017). Innovative planning instruments also include the group of technology-based instruments, such as web 2.0 media, open source software, open data, collaborative mapping instruments, decision support systems, blogs, GTFS data and in general open data (Falco, 2016). Serious games are another technology-based media (Hanzl, 2007; Söbke & Londong, 2014) to foster meaningful participatory processes. Al-Kodmany (2002) describes an overview of the various planning instruments from pen and paper to their digital implementations, from paper maps to computer-supported geographical information systems (GIS), from photographs to digital images and from physical models to digital 3D models, which support virtual reality (VR). Bartosh and Clark (2019) name in particular the benefits of MR-supported visualization of urban data, which may be considered as a prerequisite for purposeful urban planning. Silva (2010) defines the intensive use of information and communication technologies in planning processes as one feature of the so-called e-planning or e-participation. Silva adds GIS, e-participation devices and VR media to the list of technical instruments applicable to participatory urban planning processes.

1.4 Features of MR Forming Innovative Planning Instruments

One of the innovations in participatory urban planning processes is the use of VR media to support the involvement of citizens in shaping their living environment (e.g., Drettakis, Roussou, Reche, & Tsingos, 2007; Jamei, Mortimer, Seyedmahmoudian, Horan, & Stojcevski, 2017). However, not only VR media are used but Augmented Reality (AR) also finds its role in urban planning (e.g. Allen, Regenbrecht, & Abbott, 2011; Ishii et al., 2002; Shen, Wu, & Liu, 2001). AR and VR as well as the respective intermediate stages of the virtuality-reality continuum (Milgram, Takemura, Utsumi, & Fumio, 1994) are summarized and referred to in the following as mixed reality (MR). MR has been investigated and employed as a media to present proposed urban development in intuitive and interactive ways in the scientific discourse for years now. VR allows policy makers and local communities, as well as urban planners themselves and further stakeholder groups, to experience and to better understand the changes in the environment under planning before the development takes place, and thus to enable information sharing and consensus building throughout the planning process (Jamei, Mortimer, Seyed-mahmoudian, Horan, & Stojcevski, 2017; van Leeuwen, Hermans, Jylhä, Quanjer, & Nijman, 2018). The increasing technical maturity of MR hardware and software and their availability at moderate prices are preconditions for making MR media a regular instrument in participatory urban planning processes.

MR media offer features qualifying them specifically for utilization in planning processes. Several of these advantageous features should be highlighted by viewing at MR as a learning medium. Participatory planning processes may also be regarded as learning processes, for example social learning or situational learning, as is widely discussed (Beckett & Shaffer, 2005). It is even worth discussing to what extent learning is the actual goal of participatory planning processes. Zender, Knoth, Fischer, & Lucke (2019) have analyzed the characteristics of a number of VR-based learning scenarios and explicitly name the eight following features of VR supporting learning. While VR is a specialization of MR, we consider this list to be representative although not to be complete for MR. **Freedom of Design** implies that VR can be used to recreate any scenario if appropriate sensory impressions - mostly visualizations—can be created. **Adaptivity** refers to the ability of a technical system to adjust exactly to the scenario to be represented and, in particular, to adjust to the target group. **Sensor-motor Manipulation** is the integration of movements of the body into VR scenarios. **Reproducibility** indicates the unrestricted repeatability of the VR scenarios used. **Standardization** implies the same reaction of the VR scenarios according to externally defined standards. **Presence** refers to the immersion of the participants in the scenarios when the virtual world depicted replaces the real world as the dominant force for sensory perception (Mestre, Fuchs, Berthoz, & Vercher, 2006). With the help of VR, **Privacy** can be achieved, i.e. learning experiences can be made without external observation or significant components of the learning experiences do not have to be contributed facilitating real actors. **Reduction of Risks and**

Table 1 Features of VR according to Zender et al. (2019) and possible benefits for VR-supported planning processes

Feature	Benefits
Freedom of design	The freedom of the design allows VR media to be used in any planning scenario and in particular to create more variants compared to conventional planning processes
Adaptivity	Individual planning variants can be easily created by using parameters. Specific details of planning variants can also be investigated by changing the focus of the VR scenario
Sensor-motor manipulation	Sensor-motor Manipulation is not a feature commonly encountered in planning processes. However, it can be useful to validate the handling of objects or the spatial interactions with objects, for example if a door can be opened easily or if a staircase offers sufficient space for a two-person passage
Reproducibility	Reproducibility ensures that a variant can be validated over and over again, for example to increase the decision-making reliability of a citizen participating in the planning process
Standardization	Standardization allows adopting defined solutions from other contexts, for example by means of a component library, and test them as variants
Presence	Presence ensures that attention is focused to a large extent on the variants being evaluated or on the solution being designed. Collaborative scenarios may also support interaction between citizens
Privacy	If necessary, the planning variants may also be evaluated without impairing the public and—vice versa—the public not being aware of the evaluation
Reduction of risks and costs	The use of VR scenarios lowers the costs compared to real scenarios and renders the creation of physical models largely redundant. The dangers of real on-site inspections are also reduced, for example in road traffic or during inspections of facilities being planned, such as wastewater treatment plants

Costs indicates the characteristic of a simulation: risks are minimized because the scenarios are simulated and not real. Costs may be reduced because the scenarios are not provided in real terms but can be built up virtually in an automated manner.

The presented properties of VR represent a toolbox whose individual instruments can be used independently and purposefully in VR-supported planning scenarios, as described in Table 1.

2 Mixed Reality in Urban Planning

Urban planning as a task is seeking to create consensus among different disciplines and stakeholder groups, while types, motives and scales of projects vary. Therefore, participatory urban planning processes and its following decision making processes are challenging procedures that can cause projects being delayed and lead to additional costs if aspects were overlooked or ignored at the beginning of planning. Although MR became object to different fields in past years, it has barely been used in urban planning on a regular base. However, applications mainly developed as part of research projects, present a wide scope of application contexts. In the following we present a selection of MR applications, which are used in different phases of planning processes.

2.1 Communicating Plans

Two-dimensional maps are an instrument established in urban planning. For example, development plans are visualized using 2D maps. As a prerequisite for building licenses, development plans define rules that construction projects must adhere to. It reaches from physical dimensions of potential structures to methods of constructions. Illustrated is this information on maps by different, mostly standardized icons and colors as well as textual descriptions. Non-professional planners may find this amount of information in combination with the high degree of abstraction difficult to understand. To address this challenge, Broschart and Zeile (2015) introduced the augmented development plan. By holding a mobile device over marked development plans, users can choose between different information layers according to their individual interest and relevance. Further, three-dimensional counterparts translate abstract information into visual dimensions.

2.2 Finding Designs for Public Spaces

Public spaces are fundamental assets of urban areas. As streets, squares and parks, these public spaces are indispensable for the quality of life in particularly densely populated cities. As part of the Right of the City for all citizens (Holm & Gebhardt, 2011), key factors as uses and activity, comfort and image, access and linkages as well as sociability determine the quality of life (PPS, 2019). Thus, the design of public spaces is an important aspect of urban planning. In this context, aiming at enhancing design processess of public spaces and as part of a research project, the Mixed Reality Tent (MRtent) was established. The MRtent targets at fostering dialogues among urban planners, architects and citizens regarding ideas addressing urban challenges. Technically, the MR-Tent consists of various components, such as a table as a tangible user interface enabling users making changes to urban plans based on a digitalized geographical map. A video projection depicts the proposals three-dimensionally. The projected urban plans can be directly modified through an additional instrument named Urban Sketcher (Maquil, Psik, Wagner, & Wagner, 2007).

2.3 Conceptualizing the Build Environment

Decision-making in urban development requires comprehensive and analytical approaches, which are specifically required for planning buildings since buildings strongly impact perception and quality of life in the buildings' near environments.

While in the past decades the impacts of proposed buildings were analysed through physical models making changes difficult to adopt, MR applications offers new options. The MR application Arthur (Broll et al., 2004) supports users in finding locations for new buildings by means of augmented scenarios of the city of London. Users can modify different parameters, such as the dimensions of the proposed building as well existing structures. To understand the impacts, different dynamics, such as the pedestrian flow, can be simulated. Focusing on "rule-based emergent planning supported through mobile reality and gamification", Imottesjo and Kain (2018) developed the MR application Urban CoBuilder. Urban CoBuilder enables users to "design urban environment on site". Further, Urban CoBuilder allows crowdsourcing data, thus collective results of individual design and planning decisions can be gathered.

2.4 Defining Architectural Design

In addition to the physical dimensions of buildings, the buildings' aesthetical appearance strongly impacts the perceived quality of the environment (McIntyre, 2006). Thus, the decision-making process of the design should not only involve planners and architects, but other stakeholder groups as well. To improve the communication between stakeholder groups in the design process Allen et al. (2011) propose a smart-phone prototype system as AR architecture instrument. The proposed system focuses on the visualization of proposed 3D architectural designs on existing buildings. Through an interface, users are able to provide their degree of approval on the design (Allen et al., 2011). While this instrument can be solely applied for existing structures, Carozza, Tingdahl, Bosché, and van Gool (2014) present a monocular vision-based augmented reality approach "in which the urban environment is augmented with virtual static and dynamic objects, such as buildings and people". Thus, from the pedestrian's view proposed constructions can be visualized in their environment.

2.5 Visualizing and Experiencing Invisible Factors

Apart from visual elements invisible aspects like noise, environmental pollution or heat are important facets that need to be taken into consideration for urban developments. To understand and communicate correlations between urban patterns and invisible aspects the use of VR for multisensory environmental evaluation can be understood as “one of the innovations in planning process to support the involvement of local population in shaping their living environment” (Jiang, Maffei, & Masullo, 2016).

To address the issue of communicating invisible aspects in planning processes the Singapore-ETH Centre for Global Environmental Sustainability (SEC) launched the screen-based application CityHeat. Based on cellular automata-based data, CityHeat visualizes the correlation of traffic heat emissions and urban heat. Users can move through the virtual city while the heat is visualized on a microscale from blue (min.) to red (max.) (Cristie, Berger, Bus, Kumar, & Klein, 2015). Focusing on redevelopments (Jiang, Maffei, & Masullo, 2016) created a VR application for e-participation in urban sounds planning. The core are audio-visual scenarios of urban places, in which users were asked to move to different positions and to evaluate the quality of their virtual stay based on invisible effects such as the sound environment (Jiang et al., 2016).

3 Findings

The presented MR applications in the context of urban planning shows a wide range of applications with various conceptual approaches and objectives. While some applications aim to improve the understanding of conventional 2D maps, others address the design process of proposed public spaces or buildings. The MR applications are designed to be employed in early phases of the planning process. As a result, citizens can be involved in early phases. Considering the presented selection of MR applications and the features of MR in general, multiple aspects to enhance participatory planning processes are assumed. In detail, we propose various benefits for citizens that might support their active involvement in participatory planning processes. As the benefits are solely based on a theoretical approach, an evidence-based characterization of benefits of MR in the context of urban planning is yet to be done. Future work also includes the final verification whether MR applications are genuinely appropriate to shift participation activities of citizens to early phases of participatory planning processes. Thus, the proposed benefits shall be understood as impulse for comprehensive analytical research. The benefits have been differentiated in the categories *Enhancement of Understandability*, *Process Enhancements*, *Interactivity* and *Traceability* (Table 2). While *Enhancement of Understandability* refers to potential cognitive benefits among the stakeholder groups involved, but especially among the citizens, denote *Process Enhancements* affective gains of the participants and improvements of organizational aspects of the planning process. *Interactivity* was classified in a separate category as interactions enable participants to engage in activities on the one hand and engage in dialogue with fellow participants on the other. *Tracebility* represents a unique dimension, as continuous interactions with MR instruments can collect data that can also be aggregated to support decision making.

In how far the proposed benefits can be achieved depends on different factors. As an example, using unspecific participatory instruments to address certain questions

Table 2 Potentials of MR in participatory planning processes

Category	Benefits
Enhancements of understandability	– Reduces degrees of abstraction – Increased comprehensibility of plan fundamentals – Promotes spatial perception – Increases the spatial understanding of numerical values and technical specifications – Supports project-related visualizations of concrete urban planning interventions – Strengthens abstract thinking
Process enhancements	– Fosters problem understanding – Supports communication about the necessity of urban development measures – Raises awareness regarding actor diversity – Raises awareness to consider all interests – Increases understanding of technical, social, economic and ecological interrelations to be considered
Interactivity	– Allows placing suggestions straight away – Suggestions can be presented in a vivid way – Low participation threshold and high accessibility – Fosters interactions with other stakeholder groups – Helps to select and evaluate variants more transparently
Traceability	– Identifies hotspots (What facets are interesting most?) and coldspots (What has not been investigated by stakeholder groups?) of the variants by analyzing usage data ("planning analytics") – Helps to evaluate variants more transparently – Increased traceability of planning variants and decisions

can raise demotivation of participants. Thus, it is important to use MR applications in a strategic manner, requiring the conceptual approach, content and technical framework to be adopted to the issues under discussion. Another factor is the accessibility. One major challenge of laying out publicly physical plans is usually its location. Being laid out in city municipals hampers citizens to participate. Therefore, MR applications should be used in strategical locations, such as at well-known community meetings at highly frequented public spaces since they attract participants. However, hard- and software itself is required to be designed to accessibility (e.g. Du, Degbelo, & Kray, 2019) Generally, MR is not to be considered as a replacement of the informal participatory instruments but instead may be understood as an innovative option to extend the existing toolset.

4 Conclusion and Outlook

In urban planning processes, the participation of all relevant stakeholder groups is regarded as crucial. However, the current implementations of participatory planning processes are deemed to be improvable. Mixed reality (MR) media represent a promising approach to improve participatory planning processes. The maturity level for MR hardware and software has advanced considerably in recent years. In this article various examples of MR-based applications in planning processes have been presented. Advantages of MR applications in planning processes identified are improvements in comprehensibility, improvement of the planning process itself, support of interactivity, also for collaborative scenarios, and increased traceability of the planning process. In particular, comprehensibility, interactivity and accessibility of the MR-based instruments are considered relevant to shift citizens' planning activities to earlier phases of the planning process and thus to counteract the paradox of participation. Future work should contribute to the systematically development of usages of MR applications in urban planning. To this end, future work should structure MR media in urban planning according to characteristics supported, such as application contexts, planning objectives and modes of collaboration. Further, it is required to analyze planning processes with regard to phases supportable by MR media and, in particular, to examine to what extent the use of MR media will change the planning process itself.

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Digital Topographies. Using AR to Represent Archival Material in Urban Space

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Abstract In this paper we discuss how Augmented Reality as a form of spatial computing can contribute to the concept of a "mediated city", and tackle possible problems that we understand as conflicts between different modes of spatial perception. In reference to Spatial Sociology we assume that space includes a physical dimension as well as a social dimension and discuss a multidimensional framework to analyze AR applications. We argue that spatial computing provides a *digital topography* that creates new ways of understanding and orientation as well as multidimensional problems. As an example we present an immersive city tour we realized in Hamm, North Rhine-Westphalia in 2018 in collaboration with the city's archive and the Ministry of Culture in NRW.

Keywords Mediated city · Augmented reality · Spatial computing · Location awareness · Ubiquitous computing

1 Introduction

On March 3rd, 2009 the Historical Archive of the City of Cologne collapsed into a big hole caused by a poorly planned construction site. With it, the city lost one of Europe's most important archival collections to range back to medieval times. Even though archivists are still trying to restore some of the documents that were severely damaged by water, the loss of cultural memory is without parallel. However, the lost archive itself was archived before it disappeared : On Google maps one can still see

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satellite-images showing the huge pit, as shown in Fig. 1. If one switches to street view the hole disappears and the building comes back to life (see Fig. 2)—enclosed by construction site fences.

With the dawn of the digital age, cities have become complex figurations that reach far beyond their social-spatial dimensions (Eckardt, 2009): The "mediated city" (Hepp, Kubitschko & Marszolek, 2018) is outlined by mobile technologies that "…have contributed to new social and cultural practices: practices that produce and sustain communities, practices that have a fundamental impact on our ways of representing the world around us and understanding our place within it" (Zwicker, Cooley, & Verhoeff, 2017, p. 94). The way we perceive a city is deeply affected by the digital "layers of representation" (Graham & Zook, 2013, p. 77) that are linked to it. As the above-mentioned example shows, these informational layers not only become the primary framework for spatial orientation within a city but also a reference point for its 'historical memory' (Halbwachs, 1992). Against this background, city citizenship is deeply connected to the question of how we make sense of the mediated city—and what opportunities for participation we have.

This article discusses how Augmented Reality—as a form of spatial computing—contributes to the concept of a "mediated city". Following a line of argumentation that is rooted in spatial-sociology, we understand AR as a complex social, cultural and aesthetic practice rather than a mere technology. We argue that spatial computing provides a *digital topography* that creates new ways of understanding and orientation as well as multidimensional problems. To exemplify our arguments, we discuss an explorative project that we realized in the city of Hamm, North Rhine-Westphalia in 2018 in collaboration with the city's archive. We conclude by discussing how far

Fig. 1 Conflicts between different modes of presentation: The destroyed City Archive of Cologne in Google Maps

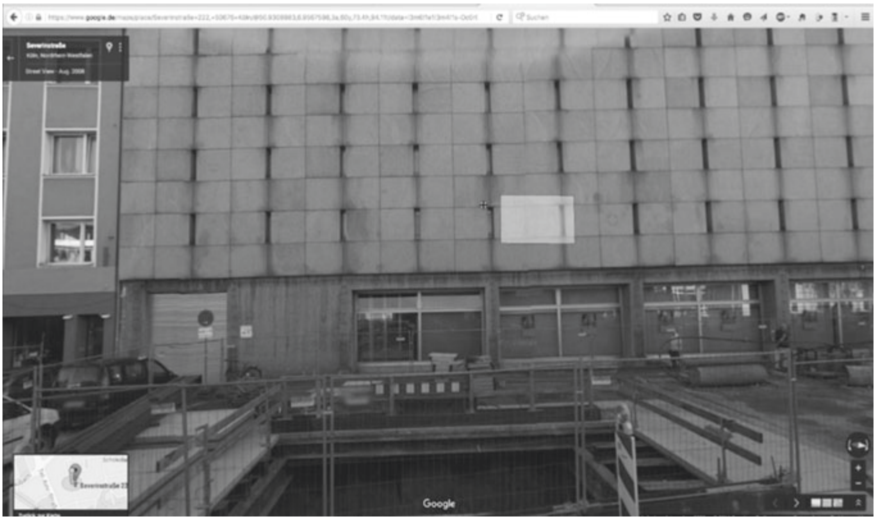

Fig. 2 Conflicts between different modes of presentation: The destroyed City Archive of Cologne in Google Streetview. Both screenshots have been retrieved at June 24th 2019

new technologies have to be developed in a participatory framework that includes the city's inhabitants.

2 Making Sense of the Augmented City

2.1 Socio-technical Implications

The concept of Augmented Reality has been shaped over decades by various contributors, such as Sutherland (1965), Caudell and Mizell (1992), and Krueger et al. (1985) who introduced the basic paradigm of Augmented Reality. The term "Augmented Reality" itself was precisely defined by Azuma (1997) and Milgram et al. (1995). However, since these beginnings of Augmented Reality there has been an interdisciplinary discussion about the possibilities mixed realities offer to the exploration of space as well as about the impact AR has on the way we perceive cities. Artist and media scholar Lev Manovich used the term 'augmentation' to describe a wide range of location-based technologies, "that dynamically deliver dynamic data to, or extract data from, physical space" (Manovich, 2006, p. 221). With a special focus on informational output as well as input technologies, he understands the Augmented City as a technological-spatial figuration that is shaped by an invisible field of surveillance cameras and cellspace technologies collecting and delivering location-based information and giving space to humans with wearable technologies, intelligent buildings, and smart objects (Manovich, 2006, p. 222). Manovich emphasizes that AR challenges our perception of cities in a fundamental way: "Does the form become irrelevant, being reduced to functional and ultimately invisible support for information flows? Or do we end up with a new experience in which the spatial and information layers are equally important?" (Manovich, 2006, p. 219).

This raises the question of how far augmented realities provide new frameworks for the *organization of everyday life experiences* (Goffman, 1986) or—in other words—what impact AR has on the way we perceive a city and try to make sense of what we see. Against the background of social theory, spatial knowledge is always closely linked to power. For instance, the "power to set data" (Popitz, 1986, p. 107) by constructing buildings that occupy space often includes the power to erase history and create new local narratives (Pranz, 2018, p. 7). Likewise the act of mapping—as has been pointed out in postcolonial studies—sometimes overrides local cultures and manifests imperial power. Scholars like Graham & Zook (2013) or Farman (2010) have suggested that the same can be said of digital mapping, geocoded content and spatial computing. In this context it becomes important *how* spatial information is collected and organized and *who* its authors are. In his analysis of the *Google Earth Community,* Farman argues that "the problem with positioning GIS as software that simply gathers empirical data and presents it as fact is that such 'scientific objectivity' is typically situated and privileges those in power." (Farman, 2010, p. 876). Graham & Zook take this idea even further when they examine online content indexed with Google Maps. Following Manuel Castells' thesis that "power in the network society is communication power" (Castells, 2008, p. 52 as cited in Graham & Zook, 2013, p. 79) they focus on the languages used in Google Maps in an attempt to reveal the underlying "linguistic geographies" (Graham & Zook, 2013, p. 79). The authors come to the conclusion that geocoded content is in many ways unevenly distributed: It privileges North America, Europe as well as parts of Asia and is concentrated in urban areas. But more importantly, it is biased by geolinguistic regions and their political paradigms: "… the case-study analysis of the geolinguistic contours of the Web demonstrates that some languages enjoy far greater visibility than others. English-language content, in particular, annotates a broad range of places while most other languages examined are mostly confined to their expected national and linguistic boundaries. At the same time, in places like Israel and the Palestinian Territories, that are home to mother-tongue speakers of multiple languages, language visibility seems closely correlated to socioeconomic status and political power" (Graham & Zook, 2013, p. 96).

2.2 Space as a Social Construct

Considering the complex cultural implications of augmented spaces it becomes clear that AR goes far beyond technical dimensions: The Augmented City emerges from a physical topography, is rooted in local culture, memory, and language and unfolds within the social boundaries of everyday life. To gain a better understanding of this figuration, we will now focus on a discussion that has attracted much attention within spatial sociology. Since the "spatial turn" in the early eighties, scholars have prioritized a social conception of space that includes temporal and material aspects (see Löw 2010; Sturm 2000). One of the most important representatives of this discussion is the urban researcher Dieter Läpple (1992). In an attempt to understand space in the framework of social and economic functions, Läpple developed the methodological concept of a "relational space" (*relationaler Ordnungsraum*) that includes a physical dimension, where objects can be placed and ordered, as well as a social dimension, where social functions and origins can be addressed. Läpple proposes a four-dimensional understanding of space:

(1) *The material-physical substrate of social relations* includes the physical topography of a place as well as the artifacts that form a spatial surrounding: buildings, traffic routes or communication infrastructure. Läpple emphasizes that in contrast to 'place' (*Ort*), 'space' (*Raum*) is artificial as it describes a place that has been cleared for further usage (Läpple, 1992, p. 201): "This original, anthropocentric space is the product of joint human work and thus a manifestation of the social or group appropriation of nature." (Läpple, 1992, p. 202—translated by the authors).
(2) *The social interaction and action structures* refer to people producing, using and adapting space. This addresses social status as well as local forms of power, traditions, and identities (Läpple, 1992, p. 196).
(3) *A normative regulatory system* connects the material-physical space with the sphere of social interactions through institutionalized conventions and regulations: forms of ownership, relations of power and control, planning guidelines or aesthetics (Läpple, 1992, p. 197).
(4) Finally, a *semiotic system of signs, symbols, and representations* is attached to the material dimension of space and provides a cognitive framework for social interaction. Besides, it is through symbolic representations that a city communicates local history and collective memory (Läpple, 1992, p. 197).

2.3 Digital Topographies

To get a deeper understanding of Augmented Realities, we suggest to understand augmentation as part of an additional layer that we call *digital topography*, as shown in Fig. 3. In accordance with Manovich's thoughts on informational networks spreading throughout the city, digital topographies in general play a crucial role in urban everyday lives: They provide orientation and influence locational advantages,[1] they inform and tell stories, they unite and separate.[2] At the same time, they interact

[1]Think of services like *TripAdvisor*, *Yelp* or *Google*, that provide ratings and recommendations for restaurants, shops and other tourist hot spots. The result could strongly diverge from the perception one gets by just strolling by.

[2]Think of location-based dating apps like *Sonar* or *Apples iOS* App *Friends*.

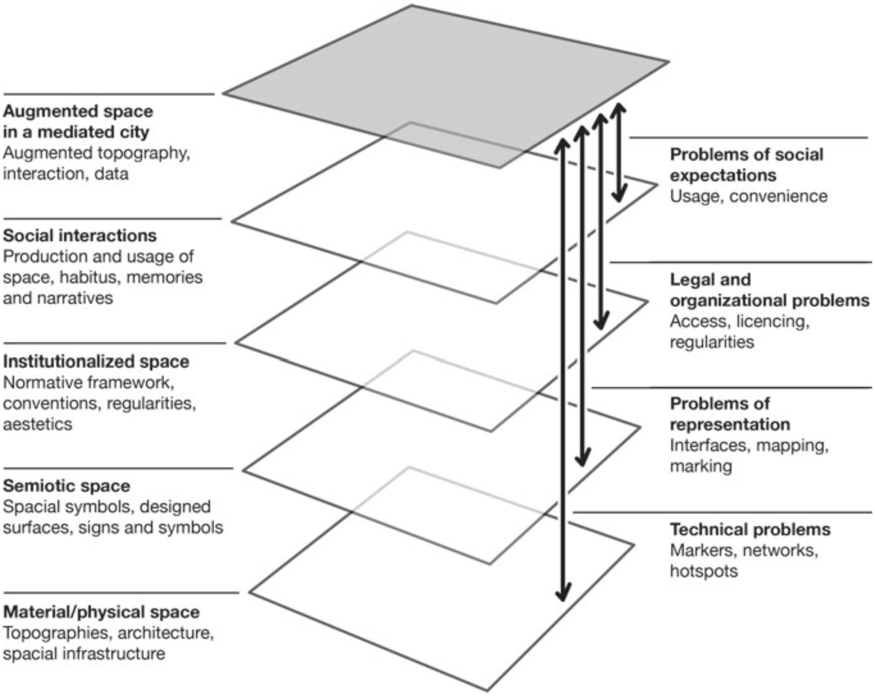

Fig. 3 The augmented space within the cities 'Matrix-Space' (see Läpple, 1992, diagram by the authors)

with and depend on the other dimensions mentioned above: Technical infrastructures make mobile computing possible, whereas valleys or huge buildings interfere with cellphone connections; supply contracts regulate coverage and bandwidth and create mobile experiences; interfaces guide (or misguide) user experiences; and user experiences are coined by cultural and societal knowledge.

In the following chapter, we want to illustrate the idea of 'digital topographies' as a methodological framework to understand mediated cities in general and discuss its implications for Augmented Realities as a specific application case.

3 Case Study

3.1 The Project "Archeology of the Digital"

In 2018 we were invited by the city of Hamm, North Rhine-Westphalia to realize a cross-sectional project with students and scholars from the fields of journalism, computer science and design in collaboration with the city's inhabitants. The 'Archive of

Transition—Hamm' was rooted in the idea of creating a deeper understanding of the region's historical heritage and carried out in cooperation with the city archive. The year 2018 was a historical marker in the region's recent history: 50 years ago, the state government of NRW adopted a structure package for a far-reaching infrastructure program: Challenged by the crisis in the coal industry, the *Entwicklungsprogramm Ruhr 1978–1973* was the first step towards a future that should no longer be driven by industry (Siebel, 2012, p. 201). Instead, the paper discusses sustainable living conditions and mobility as part of an overall social transformation (Landesregierung Nordrhein-Westfalen, 1968). In summary, the "Development Program Ruhr" has to be considered in the light of a transition from the industrial age to digital modernity. In 2018 the last coal mine closed its gates and NRW has long become an important location for a digital economy.

With the project, we wanted to discuss the impact of the political decisions in the late 60s and make visible the cultural layers of the city's recent history. Even in its earliest stage, it became clear that the project's idea was best realized by using Augmented Reality for location-based information and storytelling. The project was realized in three stages: First, we did extensive research in the city archive with a focus on material from the last 50 years (objects, texts, and pictures). We also did numerous interviews with inhabitants to collect different narratives of change. In the second stage, we identified spots in the inner city that could be used for the public exhibition, and then created a map for the tour. Finally, we produced the material and embedded it into an app that is available through Google Play Store. The first public beta was available in November 2018 and tested as part of several guided city tours.

3.2 Augmented Reality

By adding a fifth layer to our digital topography we provide an augmented topography, integrate new data sources and offer new interaction possibilities. However, the successful introduction of this new layer depends on its seamless spatial integration. This integration requires a spatial link between the existing four-layered topography and our fifth AR layer. From the technological perspective, we used six DoF-tracking for appropriate pose estimation in order to be able to sense the user's location in the urban space.

Tracking is the fundamental tool for implementing AR solutions that fulfill the three crucial criteria of AR applications as defined by Azuma: a combination of real and virtual, real-time interactivity, and 3D-registration (Azuma, 1997). The last of these aspects is especially critical in our urban space. Basically, AR tracking can be approached by using three different concepts: Marker-based tracking, markerless tracking, and location-based tracking. In our case, marker-based tracking was used.

We aimed at using unique existing objects (such as graffiti, signs, logos, etc.) as markers whenever possible in order to make the spatial link as permanent as possible. Moreover, we tried to reduce the focal distance and increase the spatial proximity between our augmentations and these marker objects, and tried to gain further insights on the optimal size and appropriate texturization of our markers.

3.3 Material Space

The physical surroundings were important in many ways. First, some of our material was closely linked to a specific place in the city, in most cases a specific building (or its remains). For instance, we worked on the virtual model of a high bunker in the city center but has been closed to the public for years. The three-dimensional model was placed just in front of the actual building, providing an insight into its architectural structure. Second, we had to find accurate markers to trigger the AR-content. Marker-based tracking requires visual structures with good features to be recognized by the camera and decoded correctly. While traffic signs or facades have a clear visual structure, they don't have enough visual features to be distinguishable from each other. We realized that posters or graffiti were perfect for being recognized, but lacked the permanence of a concrete wall. So when we made a last check before releasing the public beta, we realized that some of our markers had already been removed or simply covered by advertising posters.

3.4 Signs, Symbols and Representations

Besides curatorial aspects—like creating an interesting tour with the right 'density' of exhibits—we had to think of a suitable guidance system to orient the visitors to the virtual objects. When a virtual map on Google didn't bring the desired results, we decided to embed the main guidance system in the 'real world' of public space. Tests with a focus group showed that visitors with no AR-related media literacy had problems using our early prototypes as they didn't know where to stand and in which direction to point their device. So besides having suitable *markers*, we realized that we also needed good *markings* to orient the visitors. We finally developed a temporary guidance system with pink barrier tape to focus the attention in urban space and show our visitors where they had to expect our virtual exhibits (Fig. 4).

3.5 Normative Regulatory System

Presenting media in urban public space is affected by many regulations, especially if you are in Germany. While the city of Hamm was very cooperative and supported our project through all stages, we ran into several organizational problems. Especially when we had to discuss possibilities of turning the temporary exhibition into a permanent display, it was hard to find the right contact people: Who registers the app

Fig. 4 Using *markings*: A temporary guiding system in the city of Hamm, North Rhine-Westphalia

and acts as its publisher? Who decides where permanent markings are to be placed in city space? And who is responsible for maintenance and checking the markers on a regular basis? Normative regularities are also crucial when it comes to choosing the right app and securing digital rights: who guarantees that content will be available in the future and who 'owns' the virtual spaces where content is situated?

3.6 Social Interactions

Like every new type of media, AR requires specific 'literacy'. This includes basic knowledge of what people could expect from their devices. For instance, they need to get a feel for how long it takes for content to load and how stable one has to hold the camera to get a good response. Tests with a focus group revealed that some of the markers worked very accurately under good light conditions while shady alleys needed a steady hand and more loading time to show the content. In those situations some of our visitors gave up too early or blamed it on the device without trying again. Finally, it should be mentioned that using a tablet in AR mode in public space raises attention: Bystanders who were not familiar with AR—as shown in Fig. 5—assumed that people were taking pictures or videos, which in turn embarrassed some of our visitors.

4 Conclusion

How can AR become a suitable part of the mediated city? In this paper, we proposed a conception that considers technical, material, social and semiotic aspects as well as a normative dimension. Our aim was not only to provide a methodological framework for AR applications but also to show that the problems that may occur are complex and have to be understood on a multidimensional scale. Consequently,

Fig. 5 Bystanders (right) are looking at the 'motif'

our exploratory project revealed not only technical problems but *problems of knowledge*: Most of the visitors were using AR for the first time so they had no framework for their experiences. Visiting an exhibition involves a specific type of perspective that is closely linked with movement through physical space whereas navigating through cyberspace is merely done by moving hands and fingers. However, visiting an immersive exhibition requires a combination of both. Some of our visitors waited for an exhibit to appear while pointing the device in the wrong direction whereas others gazed at a three-dimensional model without even considering the possibility of changing the perspective by taking a step to one side. Just like the first generation of computer users had to adapt to the concept of drag and drop, our subjects had to develop a mode of orientation to cope with the concept of augmented space.

This stresses the fact that the mediated city has to be developed in collaboration with its future inhabitants. One may even go further and ask, to whom does the virtual city belong? Farman argues that Google's most important feature was the Google Earth Community, which enables users to "spatially debate the very tool they are using while simultaneously augmenting the borders in Google Earth to offer a different map altogether" (Farman, 2010, p. 873). Our project emerged from the idea of opening archival content to public use and using AR to conceptualize the city itself as an archive. During the process we realized that we would need a more user-centered approach to make these ideas work. But we also recognized that the people we worked with showed great interest in exploring new ways of seeing the city's history. As one visitor put it, AR made them perceive their city "like browsing through the pages of a book." That metaphor illustrates how AR offers great potential in creating new perspectives and ways of storytelling. However, the comparison also shows that the new media of our time is still understood within the metaphorical framework of the *Gutenberg Galaxy*. The augmented city will only be accepted if their designers conceptualize it as an experience that works on all the five layers discussed in this article.

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Designing Tomorrow's Human-Machine Interfaces in Autonomous Vehicles: An Exploratory Study in Virtual Reality

Sebastian Stadler, Henriette Cornet, Danqing Huang and Fritz Frenkler

Abstract Technical advances in the automotive industry strive in the direction of full automation. However, besides advantages like improving traffic and fuel efficiency, people do not always trust Autonomous Vehicles (AVs) to make critical decisions. With the ultimate goal of reducing anxiety of passengers of AVs, this explorative study (i) proposes possible design concepts and variants for Human-Machine Interfaces (HMI) for passengers inside the AV using a requirements catalogue, (ii) evaluates the HMI concepts and variants thanks to an experience simulation in Virtual Reality (VR), and (iii) derives the most suitable HMI concept and refines it based on observations of participants' behaviours during the experience simulation in VR, as well as questionnaires and interviews. The results show that the HMI concepts help passengers to reduce anxiety in the AV. Overall, VR turned out to be a suitable tool for this exploratory study. Further work will focus on testing HMI concepts in a variety of more complex scenarios to ensure user acceptance.

Keywords Human-Machine interfaces · Virtual reality · Autonomous mobility · Experience simulation originality

1 Introduction

Technical advances in the automotive industry strive in the direction of full automation. However, besides advantages like improving traffic and fuel efficiency, people do not always trust autonomous vehicles[1] (AVs) to make critical decisions (Giffi & Vitale, 2017). Nevertheless, trust in the technology is needed for user acceptance and, therefore, a successful market entry. In order to reduce anxiety in AVs, evaluation

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[1]Fully autonomous vehicle (i.e. level 5 autonomous vehicle) executes all driving tasks in any situation without any human input (SAE International, 2016).

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experiments are recommended to design AVs in the most suitable and usable way for future passengers. However, in the context of AVs, evaluation experiments remain difficult in real-life conditions and could lead to safety issues for participants. Therefore, an exploratory study using Virtual Reality (VR) has been conducted with a participatory design approach that included users in the design process of Human-Machine Interfaces (HMI) for passengers of an AV for public transport.

2 Related Work

Studies that investigate current user acceptance for AVs reveal concerns from users' side regarding AVs especially in the public transport sector. Schoettle and Sivak (2014) conducted a survey that revealed that 45.9% of the 1533 respondents from U.K. and U.S. were very concerned about AVs in public transport. In the study of Dong et al. (2017) with 891 respondents only 13% of respondents stated that they would be willing to ride a bus without an employee of the respective public transport agency on board. Anania et al. (2018) found within a workshop with 50 participants that less people would allow a child to ride an autonomous school bus compared to a bus driven by a licensed human driver. A global study including 17 countries and approximately 20,000 respondents from Deloitte, (2017) revealed that 62–81% of potential consumers from China, India, Germany, USA, Japan, and South Korea had concerns that AVs will not be safe. The following reasons of concern have been identified (Deloitte, 2017; Dong, DiScenna, & Guerra, 2017; Pillai, 2017; Schoettle & Sivak, 2014):

- System performance in poor weather conditions (safety)
- The interaction of AVs with manually driven vehicles (safety)
- AVs do not drive as well as human drivers (safety)
- System and AV security
- The interaction of AVs with vulnerable road users (safety)
- Lack of assistance and information.

Currently, most HMI concepts for AVs that have been published by car manufacturers consider concepts for other traffic users, like for instance the Mercedes F 015 that projects a zebra crossing on the street to indicate that passengers may cross the street in front of the vehicle (Mercedes Benz, 2015). Additionally, HMIs give information about the AV's intention and detection while being in autonomous mode to the drivers of partly-autonomous vehicles like the BMW Vision Next 100, the Rinspeed Oasis, or the Toyota Concept-I (BMW, 2016; Rinspeed, 2017; Toyota, 2017). However, published concepts for AVs that focus on passengers (and not solely the driver) are sparse, especially in the public transport sector.

In order to ensure an appropriately functioning system or product, evaluation of interaction in the actual field of application is required (Heufler, 2004). Since experiments in real-life conditions are not feasible yet though, the presented study uses the technology of Virtual Reality (VR). VR constitutes an advantageous alternative for evaluation if experiments are not feasible in real-life conditions or would turn out to be very expensive (Mihelj, Novak, & Beguš, 2013). The is based on studies in pedestrian and HMI research that have demonstrated the suitability of VR for investigations that involve AVs and human participants (Berg & Vance, 2016; Deb et al., 2017; Pillai, 2017; Stadler et al., 2019; Sween, Deb & Carruth, 2016).

3 Method

The study focuses on autonomous buses in public transport (called 'AVs' in the rest of the paper). The method consisted of three steps: (i) design of concepts and variants of HMIs for passengers of an AV, (ii) evaluation of the HMI concepts and variants thanks to an experience simulation in VR, and (iii) selection and refinement of one HMI concept for AV passengers.

For (i), users' and experts' interviews have been conducted and compared with published literature to derive a requirements catalogue for identifying fundamental needs for passengers inside AVs. With the help of the requirements catalogue, a morphological analysis[2] was conducted to derive a range of HMI concepts (including variants).

For (ii), after implementing the HMI concepts and variants in the virtual environment, experience simulation tests have been conducted in VR with participants. This method enables to identify how people might behave or interact in given situations and is especially useful for studying new services, environments, and interactions (Kumar, 2012). The scenario was defined as a riding experience inside an AV driving around a block. The simulation was created in a virtual environment in which six events were programmed for the tests (Fig. 1).

1. Start of scenario: The participants were standing in the entrance of an AV and had the task to choose a spot to sit or stand for the ride. After that, the AV started to drive.

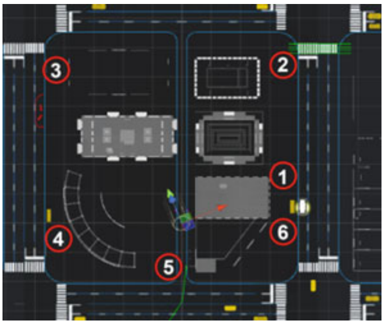

Fig. 1 Scenario for experience simulation

[2]*A morphological analysis organizes product or system features in categories and combines them to form concepts.*

2. The AV approached a zebra crossing with pedestrians (virtual agents) on the sidewalk. The AV stopped and the pedestrians crossed the street.
3. The AV approached a junction at which it had to join lanes of an intersecting street. Directly afterwards, due to a temporary construction side, the AV had to change lanes again.
4. The AV stopped at a bus stop.
5. The AV had to make an emergency brake for a jaywalker who was running across the street.
6. End of scenario: The AV returned to the starting point and the scenario ended.

The experience simulation was combined with observations, questionnaires, and participant interviews.

After a briefing and consent agreement, the participants were equipped with a head-mounted display (HMD) (i.e. HTC VIVE). The VR setup consisted of an empty tracked area of 4.0 m $\times$ 4.0 m with a chair to sit down (when the participants decided to sit during the test). Besides the HMD, the participants were equipped with noise-cancelling headphones.

At first, a tutorial familiarized the participants with the VR technology. Subsequently, the scenario was played without any HMI concept inside the AV. This represented the baseline scenario (control group) for later comparison. Afterwards, the scenario was conducted in a randomized order for each previously defined HMI concept. Video-recorded observations gathered the participants' behaviours and reactions (e.g. being surprised or amused) to the events. At the end of the experience simulation in VR, the participants were requested to fill out a questionnaire regarding their perception of the HMI concepts using a five point Likert scale (Likert, 1932). The questions were based on the System Usability Scale (SUS) defined by Brooke, (1996). Finally, the researchers conducted interviews to get insights about subjective justifications from the participants why they liked or disliked the HMI concepts.

For (iii), as a last step, all collected data (i.e. observations, the answers of the questionnaire, and answers of the interviews) were analysed to derive concept features that improved or impaired the respective concepts. Thus, the participants' preferred HMI concept was refined with the gathered feedback in order to develop the most suitable and usable concept out of the users' perspective.

4 Results

With the help of ten user interviews, five expert interviews (including psychologists, engineers, and designers), and a literature research, a requirements catalogue was developed as a basis for a HMI concept generation. The requirements were divided into three groups (must have—should have—could have) (Table 1).

Out of the requirements catalogue, two solution approaches were generated (Figs. 2 and 3).

Table 1 Requirements catalogue

Must have	Should have	Could have
Showing intention	Showing AV status	Information redundancy
Showing detection	Showing route	Notifications

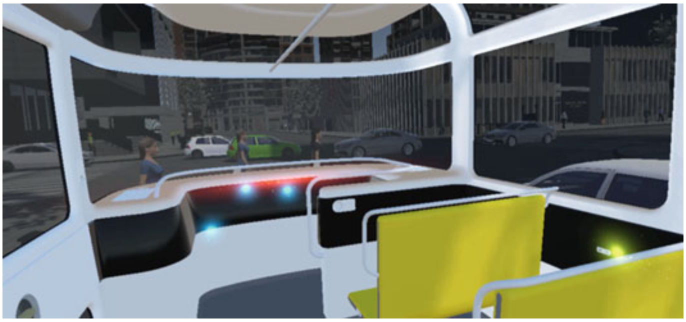

Fig. 2 Solution approach 1

Fig. 3 Solution approach 2

Within solution approach 1 (Fig. 2), a LED stripe is installed at the lower end of the front windshield. This stripe shows the AV's intention via light indications that point to a direction (e.g. LED lights up at the right side shows that the AV will steer to the right). Additionally, small light indications visualize other road users (blue lights symbolize pedestrians and yellow lights symbolize other vehicles).

Solution approach 2 (Fig. 3) consists of a semi-transparent screen-like surface that shows various information during the ride like the AV's intention, detection of obstacles, other road users as well as the AV's direct surroundings. Furthermore, four variants were built for solution approach 2. While variant A shows the AV's detected direct surrounding through its cameras, variant B shows the vehicle and its direct surrounding on an abstracted two-dimensional map. Variant C shows the AV

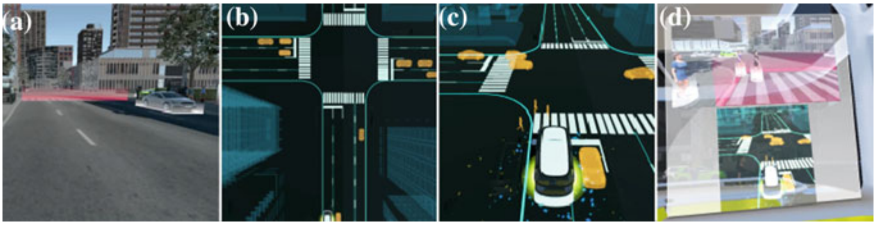

Fig. 4 Solution approach 2 concept variants

and an abstracted map from a three-dimensional bird perspective. Lastly, variant D combines variant one and three (Fig. 4).

The experience simulation was conducted with overall seven participants. The reason for keeping the sample size small was based on usability principles, defined by Rubin and Chisnell (2008) as well as Nielsen (2000) who stated that a sample size of five to ten participants is the most efficient for identifying the most relevant usability problems.

The participants' observations revealed that during the scenario without any included on-board HMI concept, the participants showed behaviours that implied discomfort and uncertainty. The behaviours consisted of covering the body with hands and arms (protective position), lifting shoulders, and/or trying to hold on to something (e.g. a handrail that was visible in VR) (Fig. 5).

Usability scores were derived from the questionnaires (Table 2). It shows that solution approach 2 had an overall higher usability score than solution approach one. Only one out of the seven participants rated solution approach 1 higher than solution approach 2.

A further question was to pick a favourite variant of solution approach 2. Five out of the seven participants chose the third variant (i.e. abstracted map from a three-dimensional bird perspective, variant C of Fig. 3) as their favourite concept. During the interviews, the participants stated that they felt uncomfortable when being confronted with the baseline scenario since they did not know where the AV would drive and if it would be capable of behaving correctly in the traffic environment. Overall, the participants claimed that the HMI concepts helped to make the AV's intention and detection system transparent. However, in total, solution approach 1

Fig. 5 Noticeable participant behaviours

Table 2 Average usability scores of questionnaires

Participant	Solution approach 1	Solution approach 2
1	37.5	82.5
2	37.5	77.5
3	75	75
4	65	65
5	75	42.5
6	72.5	80
7	55	72.5
Average Score	59.6	70.7

was not perceived as usable and supportive as it was less easy to understand and less visible. Solution approach 2 was subjectively preferred by the participants. Two major improvements for variant C of solution approach 2 were brought forward by the participants:

- The screen size and position must be improved since it blocked the view outside the vehicle and was not well visible from every spot inside the AV;
- Additional content like speed of the AV, overall route of the AV and real-time information should be added.

With the help of the user feedback, the favoured HMI concept was refined (Fig. 6).

Figure 6 shows the final HMI concept with adapted screen size and positioning above the AV's windshield. Additional information like overall route, current speed, as well as real-time notifications was incorporated into the concept.

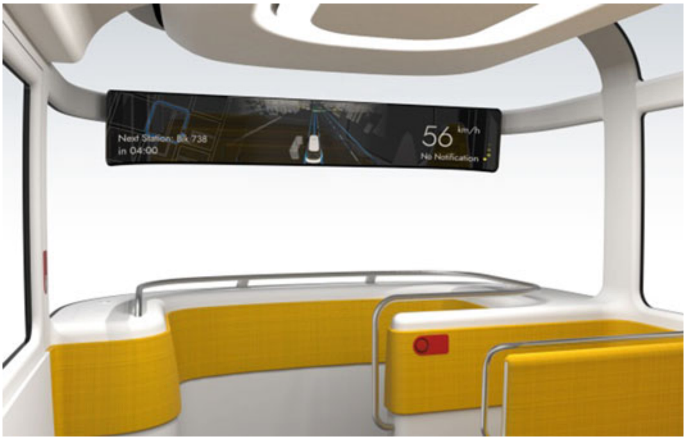

Fig. 6 Refined HMI concept

5 Discussion

This exploratory study showed that the HMI concepts were helpful for the participants for feeling more comfortable while driving with an AV for public transport.

The solution approaches and variants consisted of information about the AV's driving behaviour to minimize uncertainties for passengers inside the vehicle. Even though Carsten and Martens (2018) considered lower level AVs (i.e., not fully autonomous) in their study, they also found out that comfort can only arise as soon as the passengers know and can predict how the AV will behave, and thus, no automation surprises occur.

The study was intended to generate, evaluate, and refine HMI concepts for AVs in a quick and exploratory way. Therefore, the focus was not to test the concepts with a statistically representative quota sample of participants, but to identify basic requirements, user preferences and usability indicators for future HMI systems. This provides a basis for future design studies and concept developments.

VR turned out to be a useful tool for experience simulations since it created an immersive experience even though the chosen scenario is currently barely feasible in real-life conditions. The participants stated that the experience was engaging and convincing and thus conveyed authentic situations to them. Furthermore, it constituted a highly flexible low-cost solution that enabled the creation of complex scenarios in a short period of time. In this context, Deb et al. (2017), who conducted VR experiments in the field of pedestrian research, also concluded that the technology of VR has many advantages over real-life studies like safety, validity, time and costs.

The presented study showed however some limitations. Since every scenario consisted of the same events, the learning curve for participants was anticipated to be high. The baseline scenario was always played as the first scenario in order to reveal the discomfort for participants during the ride. Even though the subsequent scenarios involving the HMI concepts were played in randomized order, it is suggested that the stress level for participants already decreased since the participants could expect the upcoming events in the subsequent scenarios. In future studies, having a bigger set of events and varying scenarios could prevent this limitation.

6 Conclusion

Technological progress in automation in the field of transportation is not only advantageous but also creates challenges that have to be addressed to ensure user acceptance and thus, a successful market entry. The presented study showed in an exploratory way that Human-Machine Interfaces have the capability to release discomfort for passengers through showing information like the AV's intention or detection of its surroundings. In future studies, more complex scenarios and events will be created to test new concepts in a variety of situations and thus provide holistic.

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Using Augmented Reality Technology to Construct a Venue Navigation and Spatial Behavior Analysis System

Chun-I Lee, Fu-Ren Xiao and Yi-Wen Hsu

Abstract Augmented reality (AR) technology has received much attention in recent years. Following Apple's launch of ARKit and Google's ARCore in 2017, AR has become more integrated into daily living via the smart phone. This paper focuses on guided tour services which utilize AR technology and presents an AR-based build for a spatial behavior analysis system. The system primarily services viewers, content providers, and researchers. The system's functionalities include (1) allowing content providers to customize the guide's target positioning and information, (2) offering an AR-guided tour mode for viewers, (3) recording and visualizations of the spatial behavior data of the viewer which is subsequently (4) uploaded to a cloud server for further research and analysis. The benefits of the system to future academic research include indoor direction indication methods, best route query, indoor foot traffic data analysis, optimization of directing viewers from one area to the next and others, all of which offers ways forward towards improving or even changing the visual presentation experience.

Keywords Augmented reality · Venue navigation · Spatial behavior analysis systems

1 Introduction

Various research on AR-related technology in many fields have already produced evidence showing that AR is not just visually intriguing but is also able to create a simultaneously virtual and physical learning environment (Damala, Cubaud, Bationo, Houlier, & Marchal, 2008). The former president of National Taiwan Normal University Professor Kuo-En Chang and others (Chang et al., 2014) respectively researched and experimented with AR-guided tours, audio-guided tours, and non-guided tours. The research results revealed that AR is superior to audio-guided tours or text-guided tours in terms of learning effectiveness. Felix (Mata, Claramunt, &

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Juarez, 2011) and other researchers leveraged augmented reality technology with tags which were placed on exhibits in a Mexican museum. Viewers could scan the tag with their smartphones to obtain information about a certain exhibit or object in the museum. However, their research also showed that seeking out and scanning the tags were not intuitive to most of the visitors at the museum. In terms of the AR functionality's influence on the presentation experience, AR does add to the guided tour experience; however, when AR becomes the main part of the experience, viewers tend to become overly engrossed in the AR experience itself and neglect their physical surroundings (Billinghurs, Belcher, Gupta, & Kiyokawa, 2009). For instance, viewers may end up forgetting where they are physically (McCall, Wetzel, Löschner, & Braun, 2011). Thus, in considering the level of importance of the design of an AR-guided tour system, the viewer or user's movements or behaviors must be taken into account and be continuously discussed and improved. This would improve AR's supportive effectiveness. Considering the findings from the aforementioned literature, AR does have potential in supportive and learning effectiveness for viewers. Nevertheless, the design must consider both the physical and virtual elements in AR as well as the behavior of viewers or gamers so that they will not neglect to pay attention to where they are in relation to their physical surroundings and maintain an uninterrupted AR experience.

Presently, there are many related studies and applications for using AR for positioning and navigation functions. For example, visual tags which are pasted in various places can be scanned by smartphones to determine one's current location (Bellot, 2011). But in order to counteract these visual tags' vulnerability to ambient light and shadows, a hybrid Bluetooth positioning and visual tag scanning method has been developed. Bluetooth positioning is used to determine the general position. Visual tags can then be subsequently scanned to refine the positioning. This has significantly improved indoor navigation and positioning (La Delfa, & Catania, 2014). However, using visual tag has one big problem, that is, it is inconvenient for the user to perform this action of scanning. To date, AR's spatial positioning technology has made breakthroughs, mainly in Apple's ARKit and Google's Tango and ARCore. Apple's ARkit can be used with Core Location for GPS outdoor positioning and road navigation. Tango technology needs to be supplemented with depth photographic lenses and motion capture photographic lenses. Tango's core technologies include motion tracking, area learning, and depth perception, which jointly allows for the scanning of a 3D space to create a point cloud to facilitate spatial positioning. Google's ARCore (Google, 2017) includes motion tracking, environmental understanding, and light estimation, which can detect a mobile phone's direction of movement, and identify surrounding features such as the ground and walls as well as the position and brightness of virtual objects. Using this technology, a user can perform virtual object positioning without frequently scanning visual tags. With ARKit and ARCore's current AR spatial positioning technology, these applications can be used on a regular smartphone to execute physical space positioning without additional hardware.

To investigate and analyze research subjects' behavior in physical spaces, tools such as questionnaires, observations, semi-structured interviews, and video recordings can be used (McCall et al., 2011). However, when it comes to dealing with large

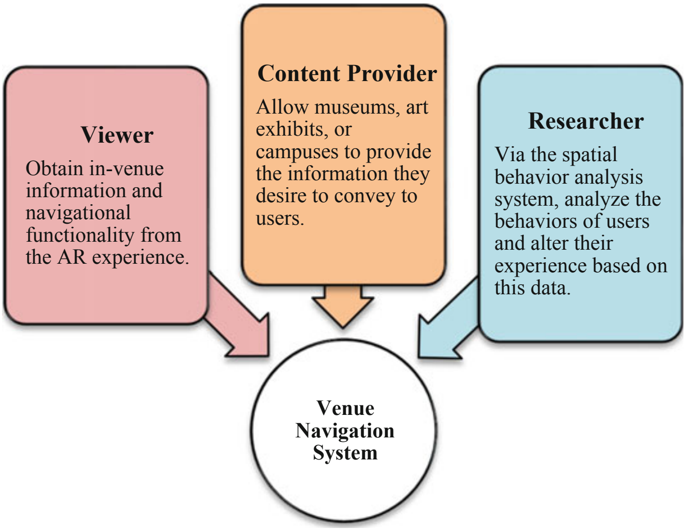


Fig. 1 AR venue navigation system service explanation

volumes of data, this method concludes large amounts of time, labor, and cost. There have been studies that involve placing inertial sensors in the pockets of research subjects to measure their walking direction, height, and distance by the angles made from the openings and closings of their legs, though the accuracy of these measurements still has room for improvement. Moreover, this method is only used in research analysis (Diaz, 2015). In order to directly integrate analysis systems with navigation systems, the system used in this study combines ARCore and ARKit technology and the navigation function on a viewer's smartphone. In addition to having AR-guided navigation, this method can also collect the viewer's geographic movements in physical space. This paper shows how to create a guided and spatial behavior analysis system with augmented reality to service "viewers", "content providers" and "researchers" (Fig. 1). The function of this system is described as follows.

1.1 Content Providers Can Customize Navigational Positioning and Information

This system uses positioning settings in smartphone applications. In the case of convention centers, the process flow map is seen in Fig. 2. Content providers can place visual tags on the ground's surface at the exhibition area's entrance. Then, after activating an app and while AR recording is in progress, the visual tag will be scanned (Fig. 3). At this time, the 3D coordinate spatial mapping of physical and virtual environments is constructed ($x = 0, y = 0, z = 0$). All users including viewers and researcher need to scan the tag because the system needs an anchor to identify

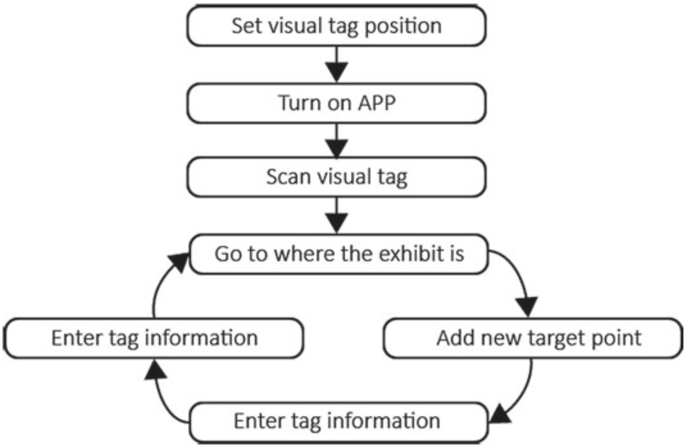
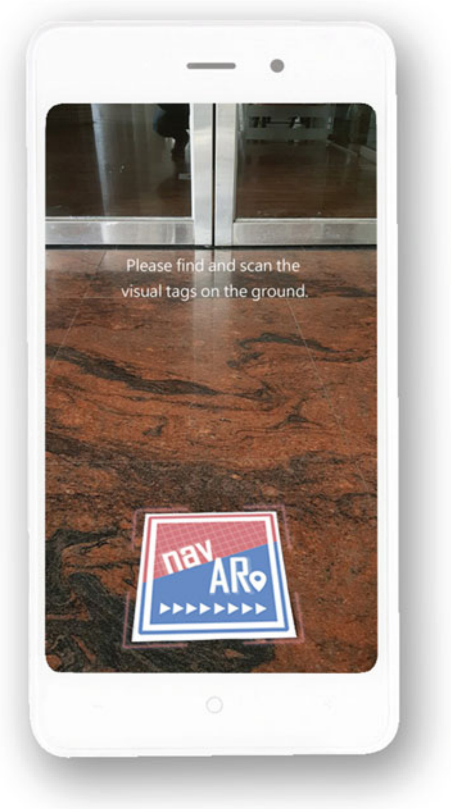


Fig. 2 App target positioning setup process

Fig. 3 Place visual tag on the ground's surface



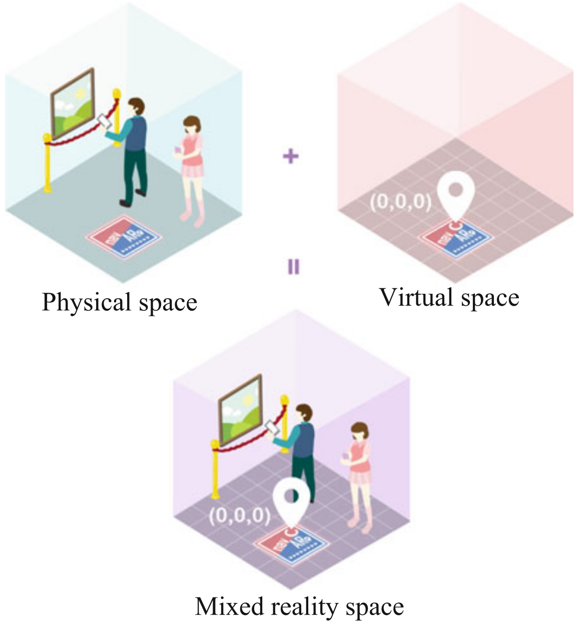


Fig. 4 The intersection and initial position between physical space and virtual space

the intersection and initial position between physical space and virtual space (Fig. 4). When content providers go up in front of the exhibit or object, they can press a button on their screen to add a position point which enables them to immediately customize the navigational positioning target and tag information. New ones can be added or deleted at any time (Fig. 5). After confirming all of the navigational target points, all entries can be saved.

1.2 AR-Guided Tour: Viewer Navigation Mode

When switching to the viewer navigation mode, smartphones will indicate to the user while in AR camera mode where visual tags in the exhibition space can be found. Once the visual tag is scanned at the entrance of the exhibition area, smartphones will directly display on their screens the locations of each exhibit target point and related information on the top of each exhibit (Fig. 6). The viewer can follow on-screen information to go to the target points as per personal preference. This function will help the user save much time when searching for exhibits in crowded areas. When the viewer is close to the target point and clicks the target point, smartphones can also display the exhibit detailed information directly on the screen and provide audio-guided tours (Fig. 7), so that viewers do not need to mingle with the crowds.

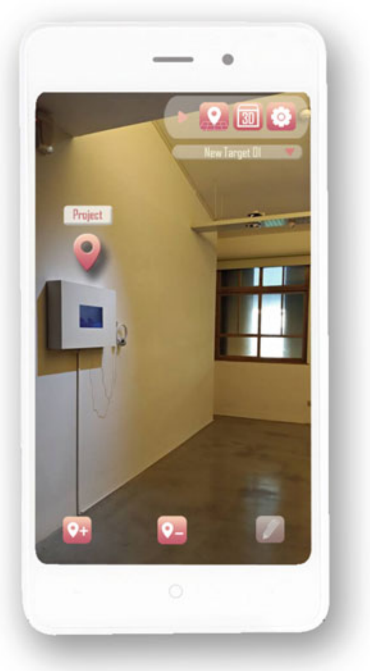


Fig. 5 Content provider sets target positioning

Fig. 6 User enters into viewer navigational mode

Fig. 7 Exhibit detailed information and audio-guided tours

1.3 Recordings and Visualizations of Movement of Users in Physical Spaces

When a viewer is engaged in a guided tour, their smartphone will simultaneously record the coordinates of their position, the paths taken, directions, distances and temporal data while in the physical space of an area and automatically visualize the paths, which contains the floor plan (Fig. 8) and the AR-rendered path (Fig. 9). While in analysis mode, the researcher can view a record of the single or all viewer's recorded paths taken in the venue, which informs content providers and the researcher about the viewer's behavior at the physical venue.

1.4 Uploading Data onto a Cloud Server for Further Analysis

In order to help future navigation systems be beneficial to the analysis of viewers' behaviors in physical venues, the app can upload the behavioral data to a cloud database after obtaining consent from the user. This would facilitate the collection of a large number of viewer data which can be analyzed and used to provide feedback to the user which can modify their viewing mode in real time.

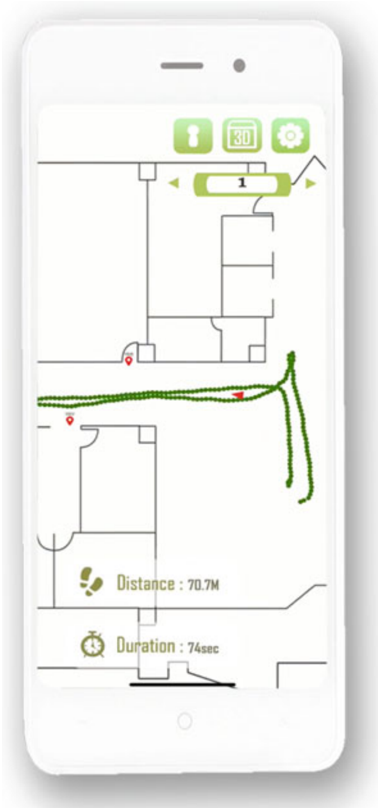


Fig. 8 2D visualizations of the viewers paths (left)

2 Conclusion

This paper provides a system that combines AR navigation and behavioral analysis, allowing viewers, content providers, and researchers to navigate and visualize viewer behavior in a physical space. However, there are three major limitations with the system utilized in this study: (1) ARCore and ARKit technology require visual tags to allow for virtual and physical spaces to superimpose on each other, which necessitates educating first-time users of AR to scan these visual tags; (2) in terms of spatial positioning, ARCore and ARKit are offset by significant distances between the initial point and the target point. Therefore, larger exhibition areas would require partitioned spaces with different visual tags set as initial points; (3) since this system is built based on ARCore and ARKit technology, the user's smartphone would need to be able to support this technology which limits the number of compatible phones that are now on the market. In the future positioning technology will be optimized to provide not only more accurate navigation and behavioral analysis results but also gamify the viewing experience. Moreover, this optimized system will guide the viewer to specified target points, achieve the regional split-flow, and create a feedback loop for the viewing experience at convention centers (Fig. 10).

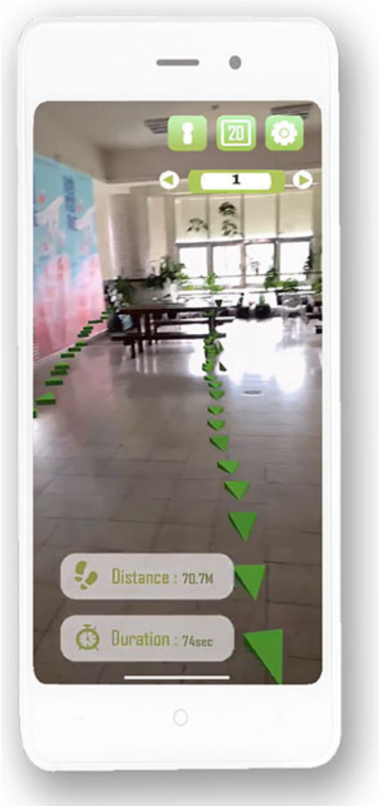


Fig. 9 View path on smartphone screen (right)

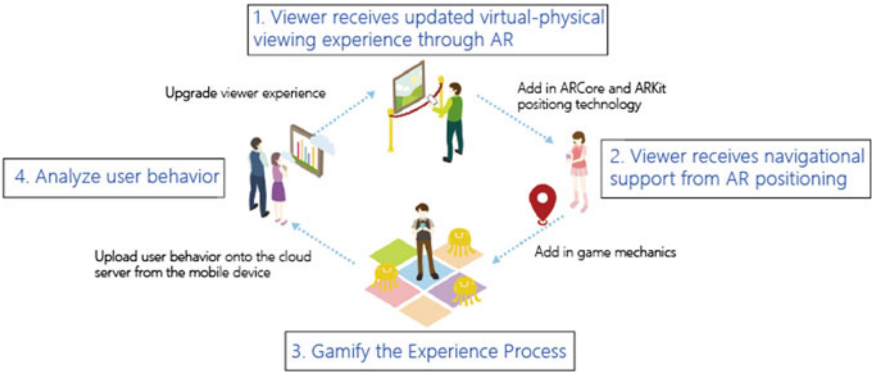


Fig. 10 Convention center experience feedback loop

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Endless City Driver: Procedural Generation of Realistic Populated Virtual 3D City Environment

Werner Gaisbauer, Jonas Prohaska, Ulrich Schweinitzer and Helmut Hlavacs

Abstract Building realistic living cities with people inside is useful for many applications like movies, computer games, and virtual reality (VR). However, algorithms that produce (i.e., procedurally generate) endless realistic cities are still scarce when simulating big cities. In this paper, we report on research that explores the design of a city generator algorithm that solves the problem of procedurally generating a realistic 3D endless city from "glueing together" a limited number of city tiles. Additionally, a new kind of pedestrian system is introduced that solves typical performance problems of a baseline pedestrian system. The inner workings of the city generator algorithm are described in detail, and solutions to problems encountered are discussed. We found that the city generator algorithm works in practice using a driving simulator. The research provides new insights into how it is possible to generate realistic endless cities, including simulated pedestrians.

Keywords Real-time · Virtual city · Procedural content generation (PCG) · Pedestrians · Unity

1 Motivation

In this work, we present new ways for procedurally creating whole cities in real-time for VR or usage in games or training. The city generation model presented in Schweinitzer (2018) creates a virtual city environment expanding itself infinitely through the use of a procedural, city generating algorithm implemented in the Unity

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game engine. It can be used for various possible fields of applications, e.g., to train object detection or in combination with VR as a simulation tool for educating driving students. We build on this model by adding a new city tile to improve the variety of the endless virtual city and a new pedestrian system that significantly improves performance problems of a baseline pedestrian system (that at maximum, cut the frame rate down by two thirds) included in the simulation from the Unity Asset Store. At 500 pedestrians distributed over the city the framerate would plummet from an average 90 frames per second (fps) at 0 pedestrians to 60 fps at 220 pedestrians (60 fps being the industry standard for most displays) to a mere 25 fps at 500 pedestrians on an Intel i7-6700 Quad Core processor and NVIDIA GeForce GTX 1070 build, with 16 GB RAM (see Fig. 1). While this "is still above the minimum requirement of 10 fps for interactive performance" (Schweinitzer, 2018), most interactive media or software strives for at least 30 fps for not only a fluent video playback but also to provide enough time for a user reaction to what is happening in a simulation.

As a next step since modelling city tiles by hand takes much time and effort, we started implementing the next generation of the Endless City Driver that uses PCG for the offline generation of sophisticated city tiles that are used to dynamically expand the city during runtime similar to the algorithm of the original version. Using this system, we hope to achieve more variation and therefore less repetition during the endless driving experience because it would be straightforward to generate a more extensive set of city tiles offline and then use them as input to the city generation algorithm.

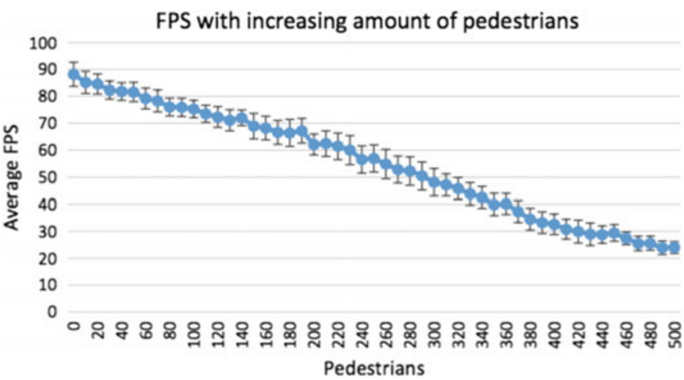

Fig. 1 Pedestrian performance

2 Related Work

2.1 Procedural Content Generation of Virtual 3D Cities

Prior work on procedural generation features one of the first procedurally generated cityscapes found in the field (Ingram, Benford, & Bowers, 1996), which is interesting because of historical reasons. Other significant prior work on procedural generation in the virtual city context is a survey on how to generate populated cities using procedural generation (Gaisbauer & Hlavacs, 2017) which does not cover the exact procedural approach used here but is related because of the populated city theme. Creating a procedural city as a background scenario using Maxim Gumin's internet famous WaveFunctionCollapse algorithm as discussed in Oliveira, Gaisbauer, Tizuka, Clua, and Hlavacs (2018) is an interesting counterpart for our research because it is also aimed at producing endless cities and uses city tiles that are glued together to achieve that, but the procedurally generated buildings are not photorealistic, and the street layout is somewhat more straightforward. The highly relevant research in Greuter, Parker, Stewart, and Leach (2003), Hendrikx, Meijer, Van Der Velden, and Iosup (2013). Watson et al. (2008), Smelik, Tutenel, Bidarra, and Benes (2014) mainly discusses how to use procedural generation to generate sophisticated virtual cities. However, this research does not go into detail on how to generate endless content. We think this problem at hand is non-trivial because it is necessary to connect ("glueing together") the tiles and the streets have to fit together seamlessly.

2.2 Virtual Pedestrians in Other Work

The implementation in Boes, Sanza, and Sanchez (2012) seems very much like a possible solution path of the problem at hand in our city simulation. It has a virtual city environment just like the one present in our implementation and has various ideas for the pedestrians, dividing them into slow, classical and fast walkers. The authors even tried to make it as close to the real world as possible by making most of them stick together like a couple or a group of friends would. They also make intelligent use of the pedestrian walkways by just implementing invisible walls on the sides of them, which, for the pedestrians, act like buildings they cannot walk into. There is also a performance statistic in the article but no mention of how the pedestrians are procedurally spawned, if at all.

The crowd patches of Yersin, Maïm, Pettré, and Thalmann (2009) are a rather theoretical approach. In this approach, pedestrians can be crowded together with other pedestrians or objects into cubes of so-called "crowd patches". These crowd patches serve the purpose that all animations in it are synced, so the CPU does not need to compute every animation for every single pedestrian but rather only calculate the animation inside the cube using a combined vector. Pedestrians can still move between the patches, but interactivity between them is limited. The approach seems to be feasible for huge crowds but not for an interactive city simulation with a lower number of pedestrians where interactivity is the primary concern.

3 Endless City Driver (The Original Version)

3.1 The City Generator Algorithm

The city generator algorithm discussed in Schweinitzer (2018) works on a simple premise: first, it takes a self-created input city tile, duplicates it four times, and after rotating the duplicates, it aligns them on the north, south, west, and east borders of the original city tile. The rotation is vital because the connecting roads would otherwise not fit, as the original city tile has only one road leading to the north, two to the west and south, and three to the east. After entirely spawning the city tiles, the algorithm creates the bounds of the original city tile and checks on every frame if the driving vehicle is still inside those bounds (i.e., the original city tile). If it is not, it despawns all tiles connecting to the new city tile (even the original), assembles new city tiles to the edges, and creates new bounds for the current tile the vehicle is on. Figure 2 shows the expansion of the city to the south of the original tile, which is directly behind the spawning point. The city tiles depicted are much more abstract than the real ones, but the connecting roads are accurately pictured. Once the users head for the city tile in the south, the algorithm realigns the other tiles, and they get entirely new connections of streets, furthering the feeling of endless driving. There

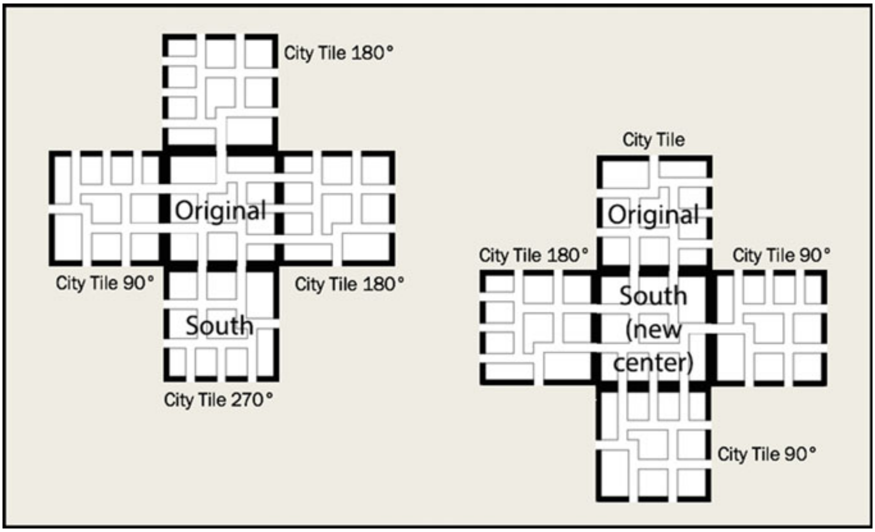

Fig. 2 City tile expansion

are always five city tiles spawned at any time but only four rotations available (0, 90, 180 and 270 degrees) so there is always a direct duplicate of a tile on the map. Precisely the duplication is always at the borders where only 1 and three roads lead out of the tile since the only way to connect those ends is to mirror the original tile at their respective border.

The slight performance bump discussed in Schweinitzer (2018) still exists when crossing the border to a new tile and remains to be tackled in future iterations. A time saver could be not to despawn every tile but move them to their new respective positions. However, at least one rotation is needed when doing this, and with the additional city tile introduced later in this work, the program would need to store eight city tiles at all times but half of them hidden from the user. It would not fix the problem entirely either as moving four 500 × 500 city tiles with hundreds of buildings, roads, and other graphical objects is not a lightweight task.

3.2 City Tiles

There exist two different handmade city tiles in total that can be used as input for the city generator algorithm, i.e., the first one (see Fig. 3 left-hand side) which was made in the scope of Schweinitzer (2018) and the second one (see Fig. 3 right-hand side) which was designed especially for this paper as added value for the users. For future work, we plan to add more city tiles to add more procedural variety to the city so that the users do not see a lot of repeated content and therefore make the content more interesting for them.

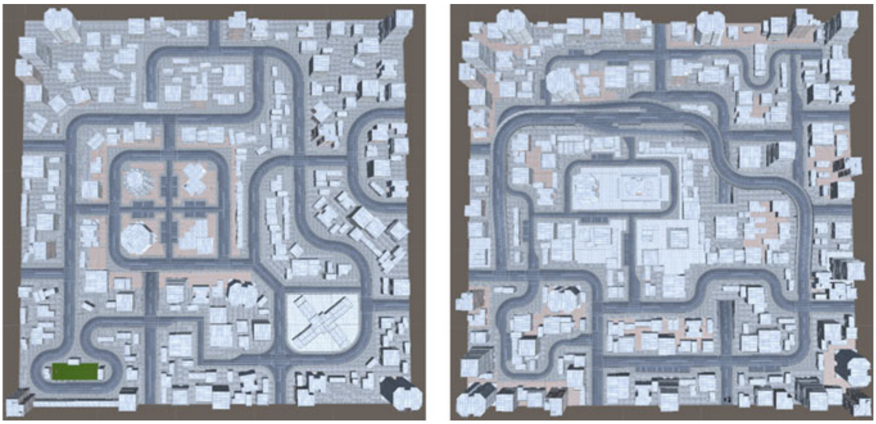

Fig. 3 First and second city tile

3.3 Pedestrian System

Since the original pedestrian system discussed in Schweinitzer (2018) had significant performance problems (at maximum, it cut the framerate down by two thirds), i.e., spawning 200 pedestrians caused performance of approximately 30 frames per second on an Intel i7-6700 Quad Core processor and NVIDIA GeForce GTX 1070 build, with 16 GB RAM. This result was mostly due to the high quality of every pedestrian model, as seen in Fig. 4. One solution could have been to just model (or download) "simpler" pedestrians. However, realism was at the top priority in this project, so losing graphics fidelity should be avoided if one wants to use this with testing of real-world scenarios or object detection of cars.

Therefore, we created an improved version as visualized in Fig. 5. On the left of the figure, there is an abstraction of how the pedestrian system was implemented in the original project. The big dot on the road represents the player vehicle, while the

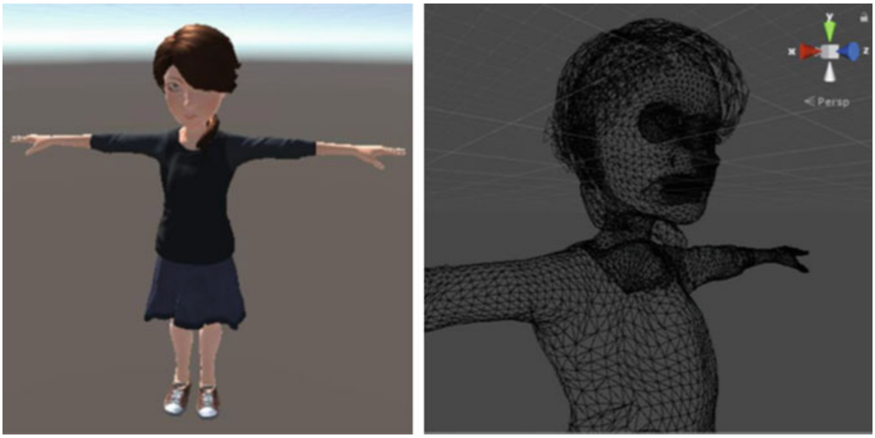

Fig. 4 Sample pedestrian model

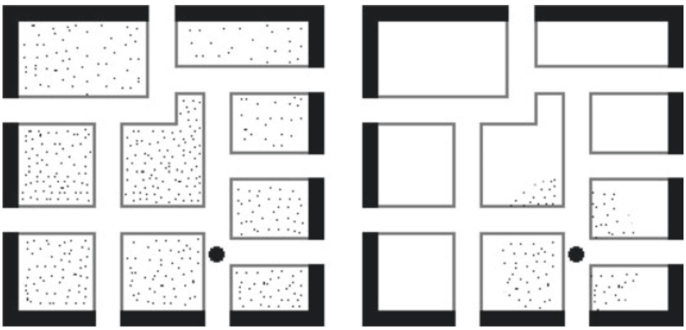

Fig. 5 Pedestrian systems comparison

hundreds of little dots represent the pedestrians walking through the tile. In the original project, there are five tiles which are filled, at all times, with pedestrian models. On the right of the figure there is the same city tile but with the pedestrians spawned only in a specific radius around the player. This technique increases performance immensely, and it also grants a much higher density of pedestrians.

While testing the new pedestrian system it had an average of 80 frames per second while spawning and despawning 100 pedestrians in a range of 100 units and about the same benchmark was achieved in the original version with 100 pedestrians spawned using similar hardware. However, at a range-radius of 100 units around the player, the 100 pedestrians only spawn at 31415 square units of the 250000 square units of a single tile which is about an eighth of the total capacity of the city tile making the density much higher in comparison. Additionally, in the original version, the 100 pedestrians were not spawned over just a single tile but five tiles, so in the new version, we can simulate a 40-fold density of pedestrians compared to the original using a setup with the same number of pedestrians. The Endless City Driver (The Original Version) in action together with some spawned pedestrians walking on the street and sidewalks can be seen in the screenshot in Fig. 6.

Fig. 6 Driving through the second city tile of endless city driver (the original version)

4 Endless City Driver (The Next Generation)

4.1 Motivation

Handcrafting city tiles takes a lot of time and effort, and therefore we had a look at procedural content generation (PCG) for generating city tiles in a more automated fashion using only several parameters to fine-tune the output. Our new approach is based on the Unity Asset CScape City System (Pavicevics, 2018), which is an ideal candidate for generating procedural city tiles or even entire cities. The CScape City System allows for building parameters (e.g., floor number, building depth, and building width) and city parameters (e.g., number of blocks, street size, and sidewalk size). The generated city tiles contain besides procedurally generated buildings of different kinds, a randomly generated river, vegetation, and bus stops as photorealistic graphical features.

4.2 The City Generator Algorithm

The basic idea is to generate procedural city tiles (based on random seed numbers) and save them as Unity prefabs before running the simulation and then let the algorithm duplicate the city tiles and align them on the North, East, South, and West during runtime as can be seen in Fig. 7. There are at all times five city tiles in memory, including the centre tile and the vehicle controlled by the user is always located in the centre tile. If the vehicle crosses the border to an adjacent tile, then this tile becomes the new centre tile and new adjacent tiles are generated (and the old ones deleted) similar to how the algorithm works in the original version of the Endless City Driver as depicted in Fig. 2 (but without the additional rotation of tiles). Procedurally generating city tiles during runtime is currently not a feasible approach since it takes too much time and a city simulation without any lags is not possible in that case on the rather low-end graphics card we used for the development of the system (Intel Iris Pro 1536 MB). A random seed integer number uniquely identifies each procedural city tile and its features so if during the design phase the designer likes to use a particular tile that should be included in the city design, she or he has to remember the random seed number. A current limitation is that the street system works on a grid, i.e., the constraint is that the street size is constant so that tiles fit together. This limitation is needed so that the generated tiles fit together seamlessly. The city, therefore, looks like a New York City layout based on city blocks (Wikipedia contributors, Wikipedia contributors, 2019). An additional feature is that it is photorealistic and contains a weather system for generating rain, wind, and also a day and night system.

Two screenshots show the Endless City Driver (The Next Generation) in action together with the newest feature, i.e., randomly parked vehicles that are procedurally generated (see Figs. 8 and 10). This feature is the first step towards populating the city with 3D objects (animate and inanimate) and thus generating a sprawling and living

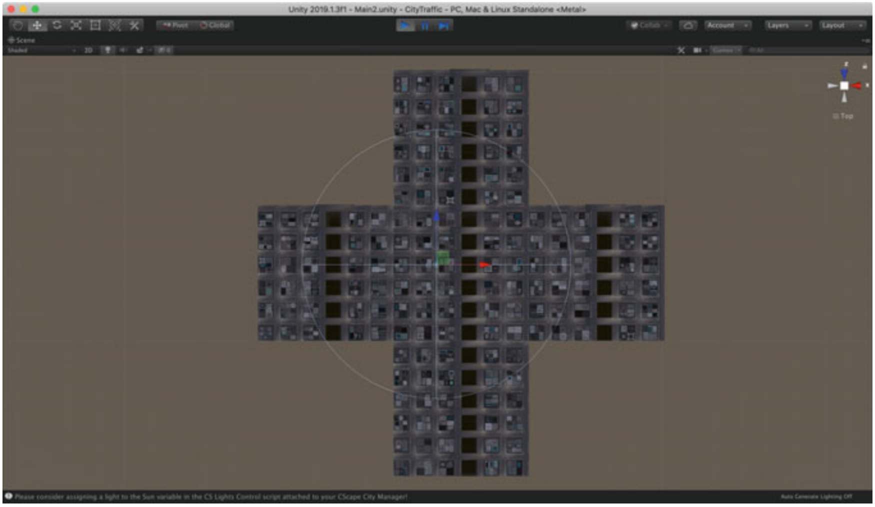

Fig. 7 Screenshot of the Endless City Driver (The Next Generation) showing the procedurally generated city tiles as seen from above. Each tile is a Unity prefab, and there is a prominent river present in the middle of each tile flowing from North to South. The vehicle controlled by the user is always located in the centre tile and is depicted by the crosshairs with a circle

Fig. 8 Screenshot of the Endless City Driver (The Next Generation) in action using the Unity video game engine. The user drives through the endless virtual city controlling a Jeep vehicle with the keyboard. Randomly parked vehicles that are procedurally generated are visible on the left and right side of the streets as well as a bus stop to the right of the vehicle

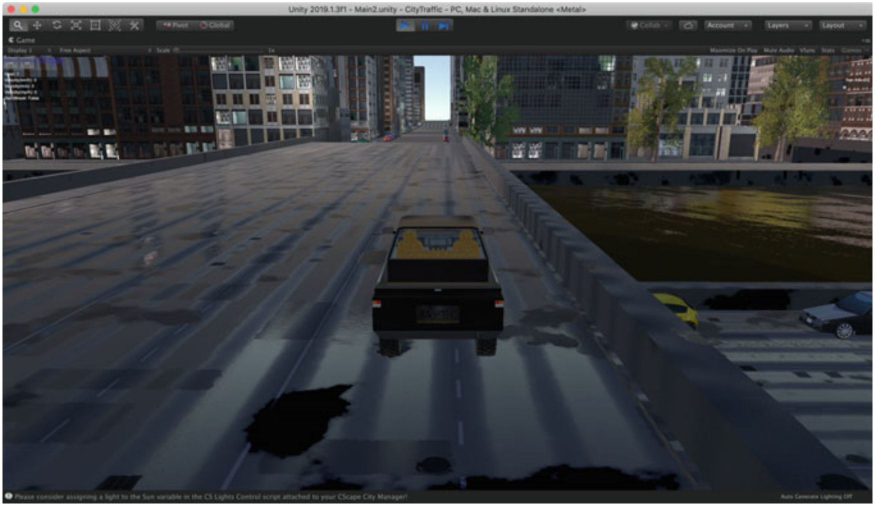

Fig. 9 Crossing the prominent river that is present in each city tile of the Endless City Driver (The Next Generation)

city (see section Conclusion and Future Work). The next logical step would be to add procedural humans walking on random waypoints and an intelligent traffic system to make the city more believable. Other already implemented graphical features of the Endless City Driver (The Next Generation) are demonstrated in Fig. 9 (crossing the prominent river), Fig. 11 (heavy rain while driving), and Fig. 12 (driving during dawn). We think that these graphical features and the features planned for future work are the requirements for a VR city so that users experience presence (see the next section Thoughts about Presence in VR Cities).

5 Thoughts About Presence in VR Cities

Presence can be described as the "feeling of being there." According to Heeter (1992), three dimensions of the subjective experience of presence (of existing), personal, social, and environmental presence, can be defined. What are the requirements for a VR city so that users experience presence? This section attempts to answer this research question in detail by merely thinking about it and without any empirical data yet (we plan to add user studies as future work).

The following features may logically increase subjective personal presence and are based on the discussion in Heeter (1992). First, it is known by now that users seeing their own hand or avatar in the world adds to the illusion of being there. The avatar can be, e.g., a vehicle like a jeep, or a school bus, in a scenario where the users drive through the city. Secondly, building photorealistic virtual cities loosely based on real cities (e.g., Boston or New York) and including photorealistic static objects like streets, sidewalks or street signs probably gives the users a sense of deja vu as if they have "been there before" because they have "been there before" in the real world and, as stated by Heeter (1992), "familiarity with a virtual world may also contribute to personal presence." This fact is likely also actual if the users are familiar with a virtual world not only from experience and practice in this virtual world but because they already saw it in the real world.

Similarly, sounds that mimic a real-world living city (e.g., footsteps, wind, rain, and traffic) and the liveliness of the users' avatar (e.g., in case the avatar is a vehicle, acceleration, deceleration, engine, impact, and skid) also add subjective personal presence because, according to Heeter (1992), "in immersion VR, a sense of personal presence is based in part on simulating real-world perceptions." Lastly Heeter (1992) states that "although the rules of this world are different from the laws of physics in the real world, there seems to be a consistent pattern which I can learn to recognize" as a reason why you feel like you are in a virtual world. Hence, it can be relatively safely assumed that, if the rules of this world are similar than the laws of physics in the real world, it would be even better for subjective personal presence (e.g., realistic car physics and model with gear shift, velocity, handbrake, and skid marks in a scenario where the users drive through the city).

Furthermore, the dynamic systems discussed in Schweinitzer (2018) (i.e., pedestrian system, traffic light system, day and night system, weather system, traffic AI system, street light system, and a system for controlling the window lights in buildings at night) are examples of how to add more realism to a virtual city. Also, these systems may reasonably add presence because, as claimed by Heeter (1992), "you know you are "there" because sounds and images in the virtual world respond like the real world to your head movements", and can be categorized into the three dimensions (all of them belong either in categories social presence or environmental presence). As a logical conclusion, to maximize presence, all these dynamic systems and other city features should be added to a VR city as substantial requirements as listed below.

- Subjective personal presence: avatar, familiar city layout, and familiar photorealistic static objects, city and avatar sounds, and realistic physics
- Social presence: pedestrian system and traffic AI system
- Environmental presence: traffic light system, day and night system, weather system, street light system, and a system for controlling the window lights in buildings at night.

6 Conclusion and Future Work

In this paper, we report on a new kind of city generator algorithm for creating realistic and immersive populated cities (see screenshots in Fig. 6 for the original version and Figs. 8, 9, 10, 11, and 12 for the next generation of the Endless City Driver). Future work could include additional performance optimizations like prefetching city tiles before entering them and thus getting rid of the last few performance problems the

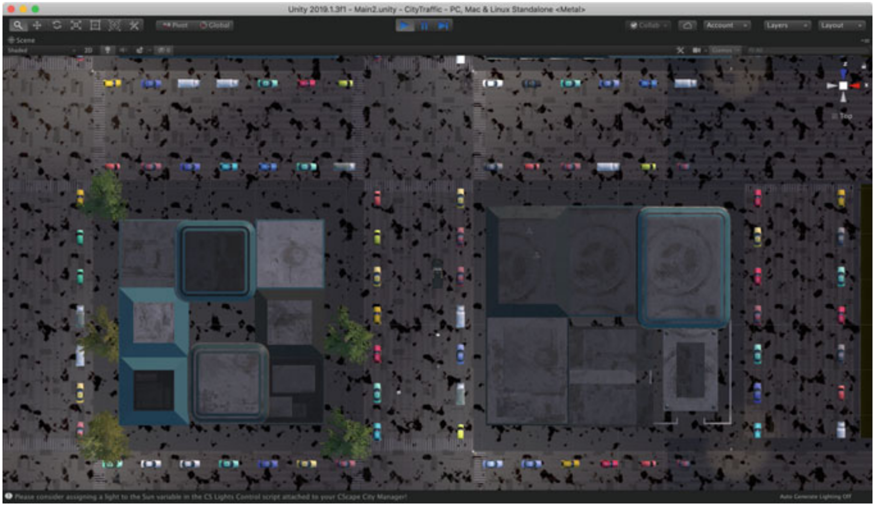

Fig. 10 Randomly parked vehicles around the city blocks as seen from above in the Endless City Driver (The Next Generation)

Fig. 11 Heavy rain while driving in the Endless City Driver (The Next Generation)

simulation still has. An invisible sphere could check for collision with the vehicle and in if a collision is triggered the prefetch algorithm would begin to expand the tiles gradually over a few frames or seconds (and not all on one frame), leading to a smoother transition to the new tile.

Early feedback of the Endless City Driver (TNG) was that the city looks like a post-apocalyptic ghost town because there was no activity in it. Therefore, to counteract

Fig. 12 Driving during dawn in the Endless City Driver (The Next Generation)

that we want to create a sprawling and living city as future work and add intelligent traffic (traffic lights and moving vehicles) and also add procedural humans walking on random waypoints. Also, we want to add different kinds of districts (NYC like vs lower buildings and more rustic style). We want to create a VR version of the Endless City Driver and do some presence user studies where the driving research question is “How to create VR cities with presence?”. Finally, we want to use the Endless City Driver as an application for testing autonomous vehicles.

Appendix

See Figs. 9, 10, 11 and 12.

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Using 5G Mobile to Enable the Growing Slate of VR and AR Applications

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Abstract With the arrival of the fifth generation (5G) radio access, there are numerous opportunities and challenges for the new worlds of Virtual Reality (VR) and Augmented Reality (AR). This abstract examines the promises of 5G networks, the future needs of VR and AR, and how 5G will integrate with VR and AR, including the impact of edge computing on VR and AR and the benefits that edge computing will offer in an intelligent 5G mobile environment. The possible challenges on devices and power consumption are also discussed. We take AR navigation as a mobility-based example to explain how 5G will enable AR and compare the different AR experiences.

Keywords 5G · Augmented reality · Virtual reality · Edge computing

1 Introduction

With the upcoming release of the relevant standard, 5G, the fifth generation of cellular mobile communication, is getting closer to an actual and functional network, huge volume of smart devices out there trying to connect to the internet every day, many of which require extensive bandwidth. Companies across the globe attempt to leverage 5G capabilities to better reach their mobile customers and through a combination of high speed, massive bandwidth and ultralow latency, 5G will allow for improvements in Virtual or Augmented Reality, autonomous vehicles, robotics, cloud gaming, and any other relative fields.

Virtual Reality or VR is immersive experience taking places within simulated environments; while Augmented Reality or AR is stemmed from VR but more

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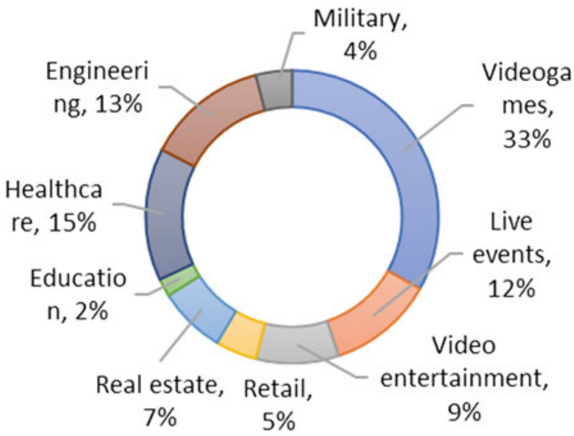

Fig. 1 2025 VR/AR estimates by use case

emphasized on building an enhanced interactive object reside in real-world environment. By now, such primary applications like helmets or glasses have already won high popularity in the market and received good responses among those entertainment consumers. Meanwhile, the imaginative VR/AR applications have made huge prospects to the future. ABI Research predicts the total AR and VR markets to reach $114 billion and $65 billion respectively by 2021, including both consumers and enterprises: according to Goldman Sachs Global Investment Research estimation in 2025 (Fig. 1), among 9 software use cases, video games, live events and video entertainment are the only 3 that are entirely driven by the consumer (about 60% of all market value). The remaining 40% is mainly deriving from enterprises which would be directly generating productive values in engineering, healthcare and real estate. Whether for consumer or enterprise use, VR and AR technologies are facing the key challenge of providing a high enough value proposition to add other devices to the current portfolio, including desktops, laptops, tablets and smart phones. Global Data report cited interviews with numerous industry players, predicting that VR and AR would be responsible for a 40% data traffic increase by 2025.

Based on these predictions, how will 5G mobile enable VR and AR applications is exciting and expectable. This paper aims to give us intuitions about what role 5G is going to play in the new worlds of VR/AR, and discuss the opportunities and challenges of 5G combined with VR/AR.

2 Literature Review

The paper firstly reviews the current position of the 5G mobile and the latest development on VR/AR applications.

2.1 5G

5G is expected to enhance not only the data transfer rate of mobile networks but also the scalability, mobility, connectivity, and spectral energy efficiency. It is anticipated that by 2020, 50 billion devices will be connected to the global IP network. Instead of using 0.7–3 GHz microwaves, 5G achieve higher data rate by using higher frequency millimetre wave near the band of 30–300 GHz. Due to richer bandwidth of millimetre wave, 5G networks could use a wider channel to communicate between smart devices at a bandwidth up to 400 MHz (comparing with that of 4G LTE of 20 MHz), which can transmit more data per second.

Massive MIMO (multiple inputs and multiple outputs) is used to increase the data transmission rate, where each network cell has multiple antennas to communicate with wireless devices, and each antenna is received by multiple antennas in the device on a separate channel, so that multiple data streams could be transmitted in a parallel manner. To generate and direct millimetre wave beam, beamforming technology is developed by continuously calculating optimal path for radio waves to reach each wireless device and organizing multiple antennas to corporate in a phased-array form, therefore signal quality is highly improved.

Smaller, more cells and antennas make infrastructure coverage for 5G networks more expensive. New material of GaN or GaAs will enable RF antennas and power amplifiers to be more energy efficient in higher frequency bands.

2.2 VR and AR

VR or AR system commonly has three basic characteristics: immersion, interaction and imagination, which emphasize the leading position of mankind, or in other words, the goal of future virtual system is to "satisfy" human's needs through an information processing system consisting of computers and other sensors, rather than forcing people to "make up" those unfriendly computer systems.

Such immersive, perceptually-real environment typically consists of multiple components, mainly can be categorized as hardware and software. In general software interacts with hardware to render virtual environment and process the user input to provide dynamic, real-time response. To achieve this, software often integrates algorithms of artificial intelligence and virtual worlds along with 3D models, toolkits and drivers. WebVR is an experimental JavaScript application programming interface (API) that provides support for various virtual reality devices, such as HTC Vive, Oculus Rift, Google Cardboard or OSVR in a web browser. As for AR, a data standard ARML (Augmented Reality Mark-up Language) is developed within the Open Geospatial Consortium (OGC).

Modern VR/AR system are based on technology developed for smartphones including sensors for tracking body positions, small HD screens for stereoscopic displays, and fast microprocessors, leading to relative affordable VR development and the first independently developed VR helmet Oculus Rift in 2012. To create the feeling of immersion, special input devices are needed to interact with virtual worlds, such as 3D mouse, tactile glove and joysticks. Other output devices like VR helmets and glasses are also developed to provide better display performance.

Although the underlying concepts and technologies that define VR and AR have been developed for decades, there are enormous difficulties that remain unresolved, for example in deploying high quality data-intensive systems. Providing enhanced 4G network coverage through so-called gigabit speed has made network-assisted VR and AR applications more feasible, 5G however will still be required to utilize more spectral and wider bands to achieve a truly high-quality VR and AR experiences.

3 Discussion

3.1 Opportunities of 5G for VR and AR

Although the development of VR and AR has been very fast in recent years, major shortcomings still exist. Many VR and AR applications are currently based on offline mode, where the scene needs to be rendered with a powerful computer. Meanwhile, due to network bandwidth and data rate limitations, most VR and AR applications do not support real-time interaction with multiple users. The 5G radio access provides opportunities for VR and AR to realize real-time multi-users experiences. This provides opportunities for applications such as the streaming of VR or AR contents to autonomous vehicles, live events, sport industry or gaming to name a few due to the possibility to live stream virtual content.

3.1.1 Advantages of 5G

Different from traditional generations of mobile communications, 5G not only promises higher speed, more bandwidth, powerful air interface, but also an intelligent network for business applications and user experiences; it will be a multi-service and multi-technology fusion. The network, through the evolution and innovation of technology, meets the rapid development needs of various services including broad data and massive connections in the future, and enhances the user experience. The three main benefits offered by 5G are wider bandwidth, shorter delay and lesser computational requirements.

Bandwidth: The bandwidth requirements are unlikely to be supported in 5G for some applications of AR or VR for the resolution and responsiveness that is necessary for extended use. For instance, Begole calculates that human can process 5.2 Gbps of data based on the physical characteristics of human perception. This is calculated based upon the ability to distinguish 200 dots per degree within the typical human foveal field of view, with at least 150 degrees horizontally and 120° vertically. Add to these 30 frames per second and some compression ratio, and you get to 5.2 Gbps. Recall that the download figure in the “dense urban broadband” use case in 5G targets 300 Mbps: the bandwidth needed for full VR is twenty times more than the target bandwidth.

Delay: It cites a requirement of millisecond end-to-end round-trip time (RTT) with high reliability for augmented reality. This is a factor 10 × compared to the 5G target of 10 ms. There are two types of delay in AR/VR. One is the delay of the application being transmitted. For instance, for a telepresence application, the other person in the communication needs to respond to us within 100 ms. This is the same delay as in a video conference today. The other is the delay perceived as the user changes point of view. For instance, if the user looks to one side, then to the other, the device has to be responsive in order to avoid the user’s sickness/nausea. This delay has to be less than 10 ms. It includes all the steps, including the rendering on the screen, which for current LCD technology takes from 10 to 20 ms. Pico LDP display technology is much faster.

Computational requirements: it is difficult to estimate the computation requirements for AR/VR; however, one interesting data point has been described by Hauswald et al. as an Intelligent Personal Assistant (IPA) system, like Siri on an Apple iPhone, or the “Ok, Google” feature on Android. The steps in such a system are: doing speech-recognition on the request, recognizing the query, processing the query by looking up some database, and returning an answer. This follows the steps of an AR system, where the vocal command is replaced by a video view from the user’s device, which would then be processed; the features extracted and the patterns identified; the question answered by looking up a database; the answer returned and then layered onto the view.

3.1.2 Edge Computing

Among the potential of 5G technologies to bring contents and computing resources to the vicinity of users, edge computing reduces latency and backhaul load. Although cloud computing enables users to access shared server pools and allows them to offload a large amount of computing power to the cloud, it’s latency to access cloud servers remains high. This is one of the main reasons why edge computing has become a promising capability for mobile users for VR/AR and tactile Internet applications. In the study by Chakareski, edge computing is used to overcome the computational limitations of VR devices by enabling users to offload computing tasks to edge servers. The author’s goal is to minimize computational and transmitting power consumption using the Lyapunov stochastic optimization model, subject to co-channel interference, reliability, and delay constraints. The authors aimed to solve the challenge of caching large 360 video files. Instead of caching and streaming the entire video to the user, they suggest partially caching and streaming 360 video based on the user’s point of view.

3.2 Challenges

Although the emergence of 5G has brought huge opportunities to the VR and AR applications, there are still some challenges.

3.2.1 GPU

Graphic Processing Unit (GPU) is the single largest performance data point generator in 3D interactive content benchmarks. Its development has been a key factor driving the growth of the VR and AR applications. Current mobile GPUs have two major challenges: overheating and battery life. The VR/AR applications on the mobile phone require a huge calculation, which further lead to a reduction in the limited battery life of the mobile phone due to overheating. The balance between safe, low-cost power supplies and increasing computational needs is yet another problem, which means VR/AR applications on the mobile phone can only be used for a short time, posing a huge barrier to provide a high-quality, rich and immersive experience.

3.2.2 Battery Life Problems

Battery problems may affect more in AR and VR applications. Passive cooling and sustaining battery life are proving to be substantial physics barriers. The intense compute demand of mobile AR/VR applications results in overheating, which further depletes an already limited battery life on mobile devices. Unfortunately, there is no equivalent Moore's Law for battery technology, and designing a safe, small, low-cost power source to keep pace with aggressive computing demands remains an uphill battle. Until then, the stress that AR/VR places over System on chips (SoC) driven devices means that only low usage time is possible, causing a significant barrier to providing the high quality, rich, and immersive experiences that are necessary to drive adoption of this new content medium.

3.3 Application Example

In this section, the map interface and the AR interface are introduced. The model movement is also displayed here.

3.3.1 Process

We design a An outdoor navigation system combined with Baidu map using AR technique where a virtual model can guide users to their destinations.

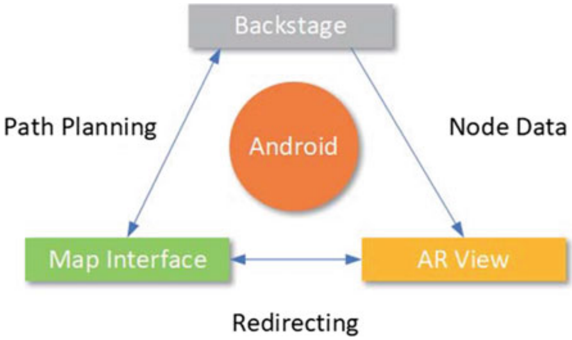

Fig. 2 The message mechanism of the entire system

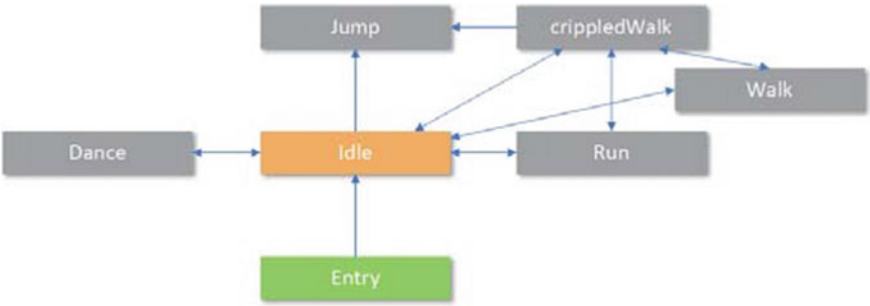

Fig. 3 Model animation FSM

The entire navigation process is divided into two threads, one is the map interface update, the other is the backstage data processing. The backstage receives and processes positioning data and obtains real-time updated path planning information and POI information. After getting the latest data, the backstage passes the data to the front desk to update the map.

In Fig. 2, we clear the links between the map interface, AR interface and backstage. The backstage passes data to both interfaces throughout its life cycle and the two interfaces redirect to each other.

The process of Model Rendering and Animation is shown in Fig. 3.

The model has a total of six actions between which we need to establish a connection. For example, the model is not always show the status of running. It will stop to the status of idling and switch to the status of walking. These actions have clear connection relationships definitely showed in Fig. 3.

3.3.2 Results

The results of Map Interface is shown in Fig. 4.

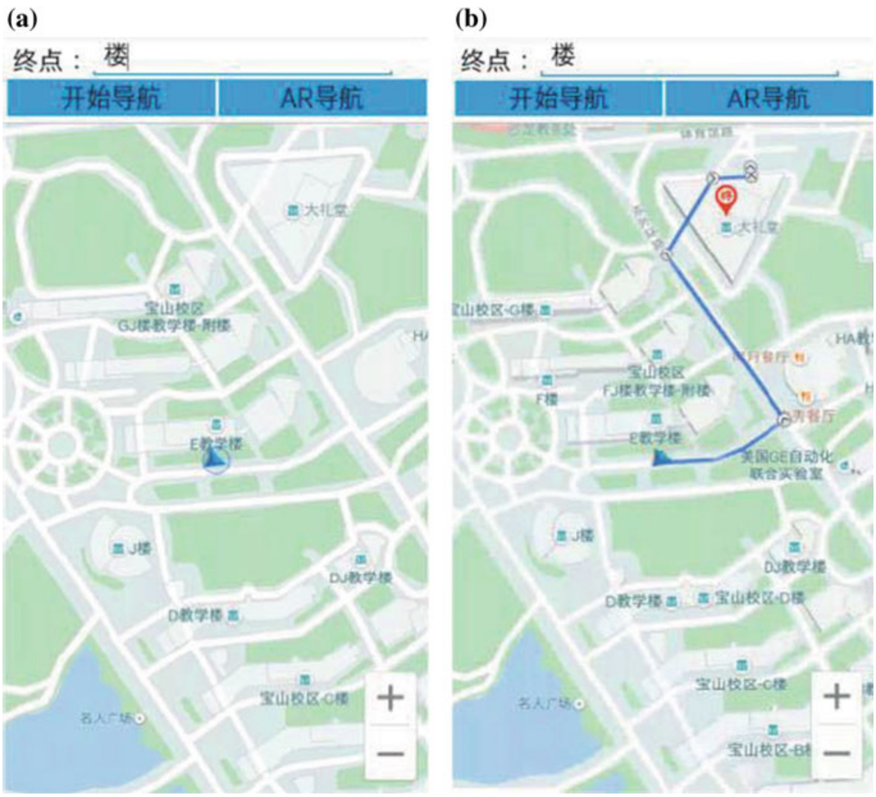

Fig. 4 **a** Current positioning function, **b** path planning function

The map interface mainly includes the functions of selecting a destination, displaying the current location, and the path planning results. The map interface is built on Android system as Fig. 4a shows. In Fig. 4b, the destination is marked with a red pattern.

The AR interface implements core AR functions. In this interface, the virtual model is rendered on the camera frames. Furthermore, some interactive buttons on the screen control model scaling, path information display and model deletion. This entire interface is shown in Fig. 5.

4 Conclusion

This paper discusses the opportunities and challenges of 5G for the VR and AR industry. First, we illustrate that the full potentials of VR and AR cannot be realized in 4G era. It then presents the key benefits offered by 5G networks, and that is elaborated in terms of speed, bandwidth and delay, as well as the potential technology of 5G-edge

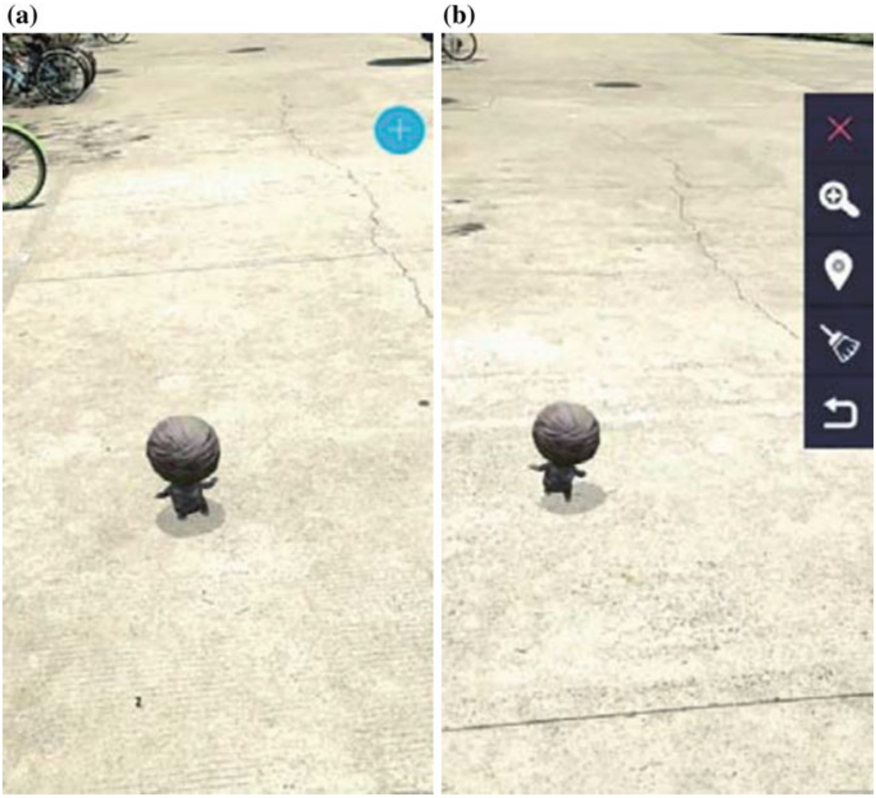

Fig. 5 **a** AR interface, **b** interactive buttons on the screen

computing. We are optimistic about 5G despite some possible challenges, including GPU, battery power consumption limit and overheating effect. In conclusion, the future of VR and AR is pretty much dependent on a reliable 5G mobile environment. We will see VR and AR in particular are set to evolve and thrive to the next level, and that will likewise help push the adoption of 5G.

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AR and VR for Health and Wellbeing

Impact of Virtual Embodiment on the Perception of Virtual Heights

Eduard Wolf, Thomas Schüler and Karsten Morisse

Abstract In Virtual Reality Exposure Therapy (VRET) for anxiety disorders, virtual reality is used to simulate threatening environments and stimuli, allowing patients to be exposed to their fear. Presence, the 'sense of being there', is widely assumed to be crucial for fear responses. It can be enhanced by full-body ownership and agency—the illusory perception that an artificial body is one's own and that a person is himself the cause for the movements of that body. This study investigated the effects of a virtual full-body representation on the perception of virtual heights. Results revealed that coherent stimuli successfully enabled a virtual embodiment, while subjects with acrophobic tendencies showed fear responses to virtual heights. However, effects were neither found on fear, nor on presence nor on self-confidence nor on physiological responses. These findings suggest that virtual embodiment has no significant influence on the efficacy of a VRET for fear of heights.

Keywords Virtual reality exposure therapy · Fear of heights · Virtual embodiment · Full-body ownership · Agency · Full-body tracking

1 Introduction

Recent studies showed that a treatment of anxiety disorders can be conducted using virtual reality (VR) technologies (Carl et al., 2019; Opriş et al., 2012). In virtual reality exposure therapy (VRET) for specific phobias, VR is used to simulate threatening environments and stimuli (e.g., virtual heights), allowing patients to be exposed to their fear (Eichenberg & Wolters, 2012). The number of advantages is enormous. For instance, the treatment can be conducted in the therapeutic office instead of visiting the fear-triggering situations or objects in the real world. Thus, the phobic factors can be applied safely, controlled and dosed. Due to recent performance and economic

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improvements of VR devices, the implementation of VRET is easier than ever. For VRET it is significant that VR can arouse real emotional reactions (Diemer et al., 2016). The factors influencing how much fear is elicited (Diemer et al., 2015) are, however, still not fully understood.

Presence is widely assumed to be crucial for the fear responses in VR (Cummings & Bailenson, 2016). This is the sensation of being in a place, to perform actions and to experience the environment with the senses (Lombard & Ditton, 1997). It is important to differentiate it from the term of immersion. Slater (1999) defines immersion as the objectively detectable attribute of a VR system to address various sensations. Presence, on the other hand, is a subjective and individual reaction to the interaction with a virtual world maybe mediated through technological immersion (Schüler, 2015). As a subjective sensation, it is not possible to evaluate it exactly. Measurements have to be conducted on a subjective, behavioural and physiological level (Slater, 1999). The few studies on the effect of presence on VRET efficacy revealed mixed results (see Ling et al., 2014, for a meta-analysis). A possible causal relationship has not been demonstrated unequivocally yet and therefore is still subject to debate (Diemer et al., 2015; Peperkorn et al., 2016). It is conceivable that the relationship is bidirectional and that fear amplifies presence, too (Gromer et al., 2019). Presence can be enhanced by the illusory ownership of a virtual body (Spanlang et al., 2014). A *body ownership illusion* (*BOI*) is the perception of a person that an artificial body part or entire body is one's own and, at the same time, the source of one's own sensations. Additionally, *agency* means that a person is conceiving himself as the cause for the actions and movements of that artificial body (Tsakiris et al., 2007). Virtual embodiment describes the physical process that is used by VR to replace the real with the virtual body in order to evoke BOI and agency. Peperkorn, Diemer, Alpers, and Mühlberger (2016) showed that a virtual hand representation intensifies the sense of presence and increases even the perceived fear. However, there is no knowledge about the impact of a virtual *full-body* representation on the fear and presence in a virtual height exposure.

To our knowledge, the present study is the first which investigates if and how a virtual embodiment, inducing a *full-body ownership illusion* (*FBOI*) and *agency*, impacts the perception of virtual heights, using *full-body tracking* (*FBT*) to enable locomotion and motion mapping. Therefore, a VR system was built, which exposes individuals to virtual heights from the view of a virtual human-like avatar, while they intuitively control the avatar. In order to achieve this, a theoretical foundation for the design of the fear of heights VR system with a virtual embodiment mechanism had to be investigated.

2 Fear of Heights Virtual Reality System

2.1 Design Requirements

The system had to enable a virtual embodiment and to elicit fear of heights using VR technologies in order to investigate the research question. Several findings provide clues for the design of phobic virtual environments (VE). Primarily, it is about increasing presence to amplify emotions. Knowledge about human perception is useful to enhance the experience of a virtual world or to use available resources more ideally.

Multi-sensoric stimuli. It has been demonstrated that the use of advanced VR technologies for the generation of multi-sensoric stimuli and for the interaction with the virtual world amplifies the presence (Cummings & Bailenson, 2016). An increased immersion makes it easier to focus on the virtual world. It should be noted that the meaning of technological immersion should not be overstated, because a convincingly designed environment, a compelling task and coherent stimuli have priority (Schüler, 2015). Besides, the impression to be able to interact with the virtual world or the pure illusionary possibility of interaction increases the spatial presence (Regenbrecht & Schubert, 2002). Furthermore, it was found that more natural locomotion techniques contribute to higher levels of presence and fear (Schuemie et al., 2005). Moreover, some of the established VRET systems for the treatment of fear of heights used passive tactile feedback (Eichenberg & Wolters, 2012; Peperkorn et al., 2016). For this, virtual objects are used that are incorporated in the real world, like a palpable landing in place with a virtual abyss. Such stimuli can evidently increase presence and apparently fear-related emotional, cognitive and physiological responses (Hoffman et al., 1998). Sound effects like Aircraft or wind that are in accordance with the virtual environment (VE) can additionally aid presence in phobic situations (Eichenberg & Wolters, 2012).

Virtual embodiment. Slater et al., (2009) suggest that a visuo-tactile and visuo-motoric accordance plays an important role in how the brain decides about the perception of BOI. Moreover, a first-person perspective (1PP) is essential for a FBOI (Maselli & Slater, 2013). Furthermore, a coherent visuo-motoric stimulation during the presentation of fake body parts through the combined use of a HMD and FBT is effective in order to provoke or to amplify a FBOI (Spanlang et al., 2014). Slater et al. (2010) revealed that the visualisation of a virtual avatar from 1PP in combination with FBT amplifies the sense of presence. Lugrin, Latt, and Latoschik (2015) recently found that detailed virtual avatars that are modeled on realistic bodies with clothes, hair, etc., can exacerbate a FBOI. A more powerful FBOI can be accomplished with a simple, undetailed human-like model. Beyond that, Lugrin, Latt, et al. (2015) found, that a visuo-motoric accordance is more important than the visual realism.

Guidance of attention and level of detail. Priorities should be set to point the attention of an individual to specific aspects (Cater et al., 2003). The render, sound and animation quality or the accuracy of the simulation can be adapted, if in specific situations it is known in advance on what the attention will be pointed to. No or only a few resources should be invested in details that are not in focus in order to maintain a smooth execution. Although, most VRET systems for fear of heights were commonly designed more realistically (Eichenberg & Wolters, 2012), it has been shown that presence and fear can be induced even if the VE is not highly detailed (Lugrin et al., 2015). More important is that the details are coherent. Additionally, the VE should contain references that imply heights (e.g. rooftops).

Motion sickness and technophobia. It can appear that a movement is simulated which does not match the vestibular-proprioceptive perception exactly, e.g. when the own movements are mapped delayed onto the virtual avatar (Akiduki et al., 2003). This can affect presence due to symptoms like nausea, etc. Thus, the end-to-end latency is a critical factor. Negative reactions to advanced technology can be minimized, if the patients have sufficient time to adapt to the instruments. An acclimatisation with the help of VEs, which do not relate to the actual therapy, but using the same instruments, can significantly decrease the fear (Jang et al., 2000).

2.2 Preparation

Different height levels were integrated into a coherent world which can be explored fluently. An urban construction site serves as the base. The main feature is a central building, which is under construction, consisting of two towers with a height of approx. 95 m (see Fig. 1). To enable a graduated height exposure, an elevator with a railing was included, which moves from the ground to the rooftop of one tower. In addition, a plank connects both rooftops, which can be crossed to enable the most possible height exposure. A platform in the real world is aligned with the virtual plank in position and dimensions to integrate a visuo-tactile feedback. Construction noise and sound effects during the elevator ride were added. These vary with the individual's position in the VE. Furthermore, a flock of birds is flying in a specified area above the building in order to let the VE appear more dynamic and realistic. Additional details like construction vehicles, etc., increase the realism. A less detailed human-like 3D character model is used which is a gender-specific robot-like avatar with a simple surface (see Fig. 2). FBT is used to enable a natural exploration of the

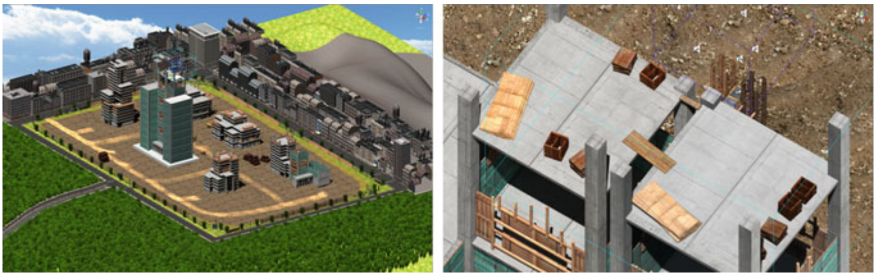

Fig. 1 Overview of the virtual environment (left) and the virtual heights scene (right)

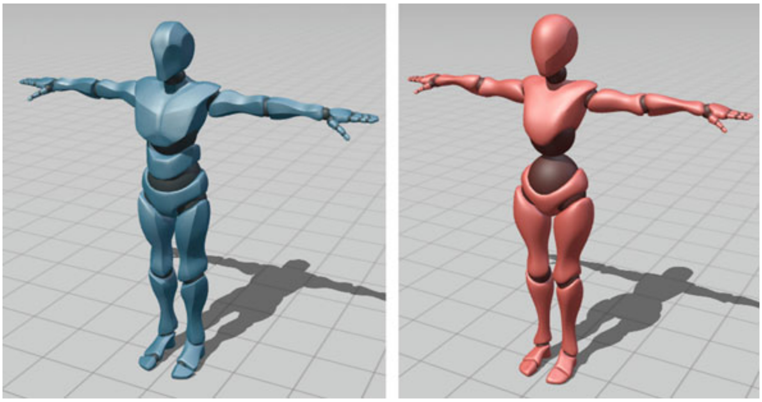

Fig. 2 Male (left) and female (right) robot-like character models

virtual world.

Besides the fear of height scene an additional neutral VE was designed. Its purpose is to serve for technical adaptation. It consists of a simple room in which an individual can naturally move within the tracking boundaries.

2.3 Technical System Environment

The fear of heights VR system is the union of different soft- and hardware components to one interactive system with the ability to simulate a virtual world and integrate the individual's body and movements.

Head-mounted display. In this study, the Oculus Rift Consumer Version 1 developed by Facebook Technologies LLC was used. At the moment of this study it was besides the HTC Vive the first HMD available and affordable for the mainstream. It consists of a stereoscopic AMOLED display with a resolution of 1080 × 1200 pixel per eye and a field of view of 110 degrees with a maximum refresh rate of 90 Hz, and integrated headphones. Inertial sensors are used to track the head orientation.

Full-body tracking. An optoelectronic 3D motion capture system (ten Oqus 5 + cameras) by Qualisys AB was used for tracking passive retro-reflective, spherical markers that are placed on anatomical references on the body. The marker data is processed in real time in order to arrange the character rig by the segment poses (position and rotation) and the root segment's position of a human skeleton.

3D game engine. Unity is a cross-platform 3D game engine from Unity Technologies. It provides an editor for creating virtual worlds as well as the ability to integrate own functionality using scripts. It has been chosen because of its official support by Oculus VR and the availability of a plugin by Qualisys using the real-time protocol.

Platform. Markers were glued to the surface of a wooden platform. Four markers were used to define the corners and the local coordinate system of the virtual plank.

Two additional tracking markers increased the reliability. The platform had a depth of 2 m, a width of 0.47 m and a height of 0.17 m.
Heart rate monitoring. The Sigma Sport R1 Blue measurement device was integrated for monitoring the heart rate with a semi-professional accuracy. The sensor transmits the heart rate in real-time via Bluetooth 4.0. A custom software component was integrated to couple events within the exposure with the heart rate.

3 Methodology and Research Design

3.1 Research Goals and Hypotheses

The primary goal was to evaluate the effect of a virtual embodiment on the perception, or to be more exact, on the perceived fear, sense of presence, behaviour and physiological responses in virtual heights. The secondary goal was to assess the relationship between presence, fear and virtual embodiment. For evaluation we hypothesized the following:
H1. Virtual embodiment has a positive effect on fear.
H2. Virtual embodiment has a positive effect on presence.
H3. Virtual embodiment has a negative effect on self-confidence.
H4. Virtual embodiment has a positive effect on physiological response.

3.2 Participants

Only persons without a diagnosed or very strong height anxiety were permitted. A consultation of an ethical review committee was obsolete. Participants were allocated to two groups. The first group labelled as ‘with avatar’ saw a virtual avatar co-aligned with their own body. In the second group labelled as ‘without avatar’ the avatar was not visible. The assignment was quasi-randomised. The attributes influencing the assignment were the time of arrival at the experiment, age and gender. Care was taken that the gender and age distribution in the groups was at a similar ratio. All participants gave written informed consent.

3.3 Measures

Six different questionnaires as well as a behaviour protocol were used in the study. Questionnaires in a foreign-language were freely translated into German. Additionally, a sensor for an objective heart rate monitoring was applied.

Socio-demographics. For measuring basic socio-demographics a custom questionnaire was utilised. Information like age, gender, computer skills, time consuming video games, and the experience with VR served for grouping of the participants.

Acrophobia Questionnaire (AQ). The AQ (Cohen, 1977) was utilised for self-assessment of the height anxiety and avoidance. It consists of two questionnaires with 20 situations each that may trigger anxiety. AQ-Anxiety rates the tendential anxiety in the respective situation and AQ-Avoidance asks, to what extent such a situation would be avoided. The total score is a measure for evaluating the basic height anxiety.

Simulator Sickness Questionnaire (SSQ). To measure the impact of the immersion on the participants' health the SSQ (Kennedy et al., 1993) was filled in after a two minutes stay in the neutral lobby. Individuals with severe symptoms had to be excluded, because their discomfort prevent them of experiencing presence.

Igroup Presence Questionnaire (IPQ). To measure the overall presence the IPQ (Igroup, 2019) was filled in after the immersion. The underlying model consists of the general item *General Presence* and the three sub-scales *Spatial Presence*, *Involvement* and *Experienced Realism*.

Simulation questionnaire. To evaluate the subjective level of fear, presence, FBOI and agency a custom questionnaire was created. The self-assessment was done retrospectively in order not to affect the exposure. Fear ratings were assessed by means of *Subjective Units of Discomfort Scales* (*SUDS*) ranging from 0 to 10. Presence ratings were assessed by analogy to the *General presence* item of the IPQ with a range from 0 to 7. Both were retrieved for the following situations: elevator start; reaching high-rise rooftop; entering plank; looking down at edge of the plank; lifting foot over edge of the plank; and reaching opposite rooftop. FBOI and agency ratings were assessed using the questions "Did you have the feeling that the virtual body was your own body?" and "Did you have the feeling that the movements of the virtual body were your own movements?" with a range from 0 to 7.

Behaviour protocol. The investigator observed the participant and noted the reactions in the corresponding situation. A protocol was used with a 'yes/no' checkbox system for questions like 'was the participant able to lift his leg over the abyss' and ordinal scales based on SUDS for questions like 'How confident is the participant?'.

Heart rate monitoring. The physiological condition was objectively monitored. The heart rate was recorded in beats per minute (bpm) and written into a log file every second during the exposure. Two baseline measurement were taken for 60 s before and at the beginning of the immersion. They represented the individual calm pulse. To prevent outliers the participants were asked not to speak or move during the recording.

3.4 Experimental Setup and Procedure

At first, participants were informed about possible side effects like motion sickness and that they could abort the participation at any moment. Then, the socio-demographical and the AQ questionnaires were handed out. Subsequently, the contacts of the heart rate sensor were misted and the strap was placed on the participants' chest. Participants had to wear an elastic motion capture suite and 32 markers with a diameter of 14 mm were placed on reference points. The marker set comprised segments that are required for a plausible movement of the avatar in order to compute spinal, shoulder, elbow, wrist, hip, knee and ankle joints. Nine additional tracking markers were added to ensure a better *Automatic Identification of Markers* (*AIM*) by asymmetrical placement and to enable the reconstruction of missing markers. A simple walk was recorded for 30 s to train the AIM model. The motion data was captured with 100 Hz. Afterwards, the first heart rate baseline measurement was recorded while sitting. At the beginning of the immersion, a start-up phase was executed. At first, the avatar was selected by the participants' gender and the height and weight were entered to compute the position of the shoulder joint by means of a regression method. Then, the participants were led to the starting point and they put on the HMD. Afterwards, a connection to the real-time motion data stream was established, the skeleton was generated and the avatar was calibrated in order to scale it to the participant's proportions and to position it accordingly. In parallel, the HMD was tracked to align the virtual camera with the viewing direction in the global coordinate system. The same was done for the wooden platform in order to align the virtual plank. Additionally, the connection to the heart rate sensor was established.

Each participant started with a training phase lasting for about two minutes. They had to accommodate to instruments and to learn how to look around and to move within the lobby scene. After that, the participants took off the HMD and filled the SSQ to preclude motion sickness. In a short intermission the participants were informed that the investigator will instruct them by microphone during the exposure, but that they can explore the VE freely. They were led to the starting point and put on the HMD again. Now, the second baseline measurement was recorded. Eventually, the virtual height exposure started. The participants positioned themselves in the centre of the elevator while they were instructed not to exit the elevator. Nevertheless, they could still look around and move. The elevator ride was started and the participants travelled to the rooftop of the high-rise building. As they reached it, they were instructed to move to the virtual plank and to enter it. After entering, they were instructed to move to the centre of the plank and to look over the right edge down into the abyss. Then, they were instructed to lift one of their feet over the abyss (see Fig. 3). In parallel, the investigator noted the participants' behaviour. The different virtual height situations are presented exemplary from the view of a male participant with visible avatar in Fig. 4. Finally, they were instructed to reach the opposite rooftop and the exposure ended. Immediately afterwards, the SQ and IPQ were handed out to prevent interim disturbances.

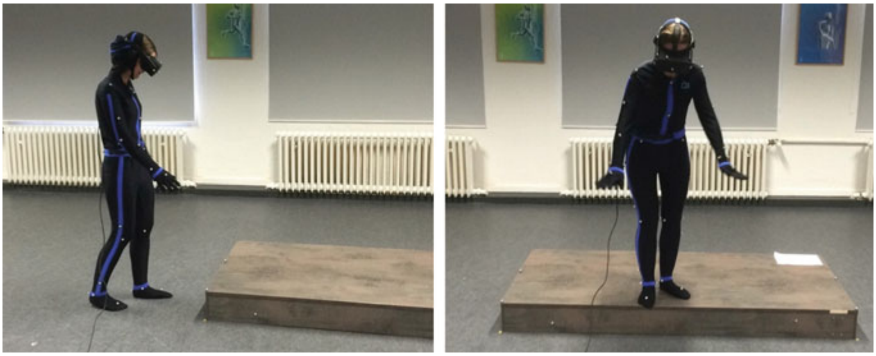

Fig. 3 A participant before entering the plank and while looking into the deep

Fig. 4 Various virtual height situations from the view of a male participant with visible avatar: **a** View from the elevator into the deep; **b** View at the high-rise rooftop; **c** View when entering the plank

3.5 Statistical Analysis

Mean and standard deviation were computed for each variable. For determining group differences, a statistical left-sided t-test for two independent samples was applied. To evaluate the effect of the group assignment on the fear in the virtual height situations under control of basic height anxiety, an analysis of covariance was accomplished. Possible linear relationships between the various instruments were evaluated by means of the product-moment correlation coefficient. A coefficient is defined as 'very low' (0.0–0.2), 'moderate' (0.2–0.5), 'strong' (0.7–0.9), and 'very strong' (>0.9).

4 Results

4.1 Group Characteristics

A total of twenty-four participants were included (age: M = 32.4, SD = 9.6; 9 female participants). Table 1 gives an overview of the age and gender distributation.

Overall, the technical experience was balanced between groups. With regard to the maximum score, the SSQ score was marginal for both groups (see Table 2). Due to

Table 1 Grouping of the participants

	With avatar	Without avatar
Sample size	13	11
Age (*years*)	33.2 (9.6)	31.5 (9.5)
Gender (*male/female*)	8/5	7/4

Table 2 Questionnaire and physiological data.

Sample characteristics	With avatar		Without avatar				
	Mean	SD	Mean	SD	t	df	*p*
Computers (*hours per week*)	32.5	19.4	27.3	20.9	0.640	22	0.529
Video games (*hours per week*)	1.7	2.7	2.3	3.0	−0.539	22	0.595
VR experience (0 = *'no' to* 4 = *'very much'*)	0.7	0.9	0.6	0.9	0.154	22	0.879
SSQ (*max.* 48)	3.8	2.7	2.6	2.8	1.004	22	0.326
AQ total score (*max.* 160)	56.6	21.1	41.9	22.7	1.592	22	0.063
AQ-anxiety (*max.* 120)	30.3	17.2	17.9	17.7	1.739	22	0.048*
AQ-avoidance (*max.* 60)	25.9	4.4	24.0	5.2	0.942	22	0.178
IPQ total score (*max.* 6)	3.9	0.8	3.7	0.8	0.452	21	0.328
General presence	4.6	1.5	3.8	1.6	1.273	21	0.108
Spatial presence	4.5	1.0	4.6	0.9	−0.332	21	0.628
Involvement	3.3	1.2	3.6	1.3	−0.503	21	0.690
Experienced realism	3.4	0.7	2.7	1.0	2.194	21	0.020*
Fear (*max.* 10)	4.5	2.2	2.6	1.8	2.214	21	0.019*
Presence (*max.* 6)	4.5	0.9	4.2	0.8	0.775	21	0.223
Self-confidence (*max.* 10)	3.5	1.7	2.6	1.5	1.394	21	0.089
Maximum rise of heart rate with respect to baseline at rest in %	34.8	20.5	45.3	15.4	−1.202	15	0.876

AQ, Acrophobia Questionnaire; SSQ, Simulator Sickness Questionnaire; IPQ, Igroup Presence Questionnaire

*$p < 0.05$ for significant group differences

**$p < 0.01$

minimal responses of the participants to the training phase, no one had to be excluded due to motion sickness. One was excluded because of premature termination.

4.2 Impact of Virtual Embodiment

It was evaluated, if and how strongly the participants experienced a FBOI and agency (see Table 3). All participants claimed that they observed a virtual body in place of their own. The results indicate a strong FBOI and agency.

Fear. AQ-Anxiety score was significantly higher in the group with avatar ($t_{21} = 1.739$, $p < 0.05$). Fear was averaged for the six situations in which the participants were exposed to virtual heights. A significantly higher fear ($t_{21} = 2.214$, $p < 0.05$) was observed for the group with avatar. A strong positive correlation between AQ total score and fear was found (see Table 4), which was significant ($r_{21} = 0.82$, $p < 0.001$). After controlling 'AQ', no significant effect of the group assignment on fear was found [$F (2, 20) = 21.819$, $p = 0.477$], rejecting H1.

Presence. It was measured for the entire immersion as well as for the virtual height situations. The former was evaluated by the IPQ and for the latter, the scores for the

Table 3 Full-body ownership illusion and agency of the group with avatar

With avatar					
Observed a virtual body in place of the own body	%	n		Mean	SD
Always	61.5	8	Feeling that the virtual body was the own body (*full-body ownership, max.* 6)	4.4	1.7
Sometimes	38.5	5	Feeling that the movements of the virtual body were the own (*agency, max.* 6)	5.2	1.0
Never	0.0	0			

Table 4 Relevant correlations within the groups.

Correlation		With avatar		Without avatar	
		r	*p*	r	*p*
AQ total score	Fear	0.77	0.002**	0.809	0.005**
Fear	IPQ total score Presence	0.52 0.76	0.066 0.002**	−0.23 −0.61	0.522 0.062
Full-body ownership	Fear Presence	0.62 0.68	0.023* 0.010**		
Agency	Fear Presence	0.62 0.67	0.023* 0.012*		

*p < 0.05 for significant group differences
**p < 0.01

six situations were averaged. Only *Experienced Realism* was significantly higher in the group with avatar ($t_{21} = 2.194$, $p < 0.05$). These results do not support H2.

Behaviour. Averaged self-confidence score was higher in the group with avatar, but the difference was not significant ($t_{21} = 1.394$, $p = 0.089$). This does not support H3. Besides, it was noted if the participants were able to accomplish the tasks during the exposition. One participant of the group without avatar was incapable of lifting his foot over the abyss. Another participant aborted the experiment after entering the plank.

Physiological response. The measurements of 7 participants were excluded, because of malfunctioning equipment. To be comparable, the mean baseline value was subtracted from the value of each time sample and the result was set in ratio to this baseline as *rise of heart rate*. The heart rate was balanced for both groups during the baseline measurement at the beginning of the immersion. Overall, the heart rate was noticeably lower for the group with avatar during the entire exposition, but the difference was not significant, rejecting H4 (see Table 2).

4.3 Relevant Correlations

Table 4 shows an overview of relevant correlations. A strong positive correlation was observed between fear and presence ($r_{11} = 0.76$, $p < 0.01$) for the group with avatar only. As fear was significantly higher for the group with avatar. FBOI showed moderate positive correlations with fear ($r_{11} = 0.62$, $p < 0.05$) and presence ($r_{11} = 0.68$, $p < 0.01$) in the virtual height situations, which were significant. Agency showed moderate positive correlations with fear ($r_{11} = 0.62$, $p < 0.05$) and presence ($r_{11} = 0.67$, $p < 0.05$), which were significant, too.

5 Discussion

Since the virtual height exposure evoked similar emotional reactions of the participants compared to real heights, it can be concluded that the system's design requirements were fulfilled. Moreover, participants that controlled a virtual avatar reported a strong FBOI and agency. An effect of the virtual embodiment on fear could nevertheless not be confirmed. The findings of Peperkorn et al. (2016) might provide a reason for this. It was demonstrated, that a virtual hand representation during an exposure to a virtual spider elicited a significantly higher fear for persons with a fear of spiders only. This suggests that a repetition of the here described experiment with persons suffering from a pathological fear of heights might lead to other results. The close relationship between basic height anxiety and perceived fear suggests, that height anxiety as a stable personality trait leads to a higher fear in virtual heights. This corresponds with findings of other studies (Diemer et al., 2016). For all participants the heart rate increased with danger, while the heart rate was lesser for participants that controlled the virtual avatar. A reason for this might be that they felt safer when seeing virtual feet on a solid underground. Conflicting with previous findings which claim a general amplification of presence by virtual embodiment, the results could not confirm such an effect. Participants that controlled a virtual avatar perceived, however, a significantly higher realism. But this might be related to that the more anxious participants of this group had a stronger feeling of realism in the virtual heights. Furthermore, with increasing presence and fear, both FBOI and agency increased, too. This implies that presence as well as fear both enable a strong embodiment in first place. That is confirmed by studies in which the BOI was amplified by stress (Lugrin et al., 2015). The observed positive correlation between fear and presence for the group with avatar only is in line with previous studies which state that the tendency of perceiving presence is higher for persons that tend to be more anxious than for persons without anxiety (Gromer et al., 2018; Peperkorn et al., 2016). This finding highlights the importance of the concept of presence for fear triggered by VR (Diemer et al., 2015). However, the current study does not allow conclusions about the causality of the relationship between presence and fear in particular due to the relatively small sample size. Finally, it seems important to elucidate for other disorders whether virtual embodiment correlates with disorder-relevant responses in VR.

6 Conclusion

The study revealed that coherent stimuli successfully enabled a virtual embodiment, while participants with acrophobic tendencies showed fear responses to virtual heights. However, significant effects were neither found on perceived fear nor on sense of presence nor on observed behaviour nor on physiological responses. The study suggests that a virtual embodiment has no significant impact on the efficacy of VRET for the treatment of fear of heights. This implies that expensive motion tracking systems are not necessary—an accurate planning and design of the virtual world is more essential. Nevertheless, further studies are needed to unravel the role of virtual embodiment on both the processes and outcome of VRET.

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AR and VR in Theatre Productions and Journalism

Humanising AR in Design: Introducing Digital and Physical People to an Augmented Reality Design Visualisation Process for Theatre

James Simpson

Abstract What is the effect on the theatrical production design process when a design team uses holographic AR visualisations to view the scenery before it has been commissioned to be built? Bringing digital images into the physical world may provide new opportunities to test ideas and create new ones. This question is being tested on a professional production team as they develop the new work; *Rejoicing at Her Wondrous Vulva, The Young Lady Applauded Herself* at the Ovalhouse Theatre in Oval, London.

Keywords AR · MR · Hololens · Theatre · Design · Visualisation · Scenic · Collaboration · Communication · Creativity · Spatial · Director · Performer · Writer · Designer · 3d · Iteration

1 Introduction

A director can get their first impression of a productions aesthetic when they first see a scale model box; an accurately scaled and crafted simulacrum of the scenic design for a theatrical production. They begin to make observations, challenge concepts, make plans and iterate on ideas using this visual medium as a point of reference (Mitchell, 2009).

For directors who work with designers who produce model boxes, this becomes a part of their method for crafting the entire piece of theatre and becomes a milestone in the design process that a lot of decision making relies on before choices are confirmed or re-evaluated (Pavelka & Chitty, 2015).

The introduction of a digital version of such a process, therefore, may be the logical next step, where directors and designers work with a model box that instead of being made from cardboard, foamboard, plaster, polystyrene, metal or even Lego bricks, may even be made from pixels.

New practices will emerge, particularly where digital is concerned and although there is not a suggestion that analogue processes need to be discarded, there will likely

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be distrust amongst established designers when approaching digital technologies who assume that it will disrupt their process. The designer will have a methodology of their own when creating ideas for a new production which happens whilst the model box is being crafted. The decisions that need to be made to create a scaled model also inform the design and develop it. The choice of modelling medium for the designer is as relevant as it is for the painter who will choose between watercolour paints or oil paints as their preferred medium. As such, pixels become a medium that sits alongside the physical and is one more choice that a designer may select when crafting ideas.

What pixels and digital technologies allow when presented through immersive technology such as Virtual Reality (VR) and Augmented Reality (AR) is the ability to design at a small scale (similar to a model box) and then increase its size to exist in full-scale so that one may walk through it and experience the design as if it were the final build.

This study seeks to examine the effect on the process of designing and creating for theatre when Augmented Reality (AR)[1] digital visualisations are introduced into the process. The effect that is measured is an intangible, qualitative disruption to the usual process of theatre design—although no two design processes are similar. The practitioners of the design, the writers, directors, designers and performers, engage in the use of AR pre-visualisation during a workshop to discuss the design and other relevant ideas that may come.

This piece of research sits within a wider framework of research to understand and establish new protocols of the theatre design process which allow design teams to collaborate together more effectively through the use of a wide range of digital pre-visualisation systems. The output of the wider research is to challenge the existing norms of the theatre industry's design processes and introduce new systems of work which have been proven to be effective in the film, games, engineering and architectural industries.

Whilst the team is aware of their contribution towards the research, their focus is primarily on their production and their use of the system is "real-world", in that they use it to consider work that they are investing their time, reputation and money into. This in no way reduces the effectiveness of the research but means that we see the real-world application of the technology through their lens which is magnified on the issues they wish to solve.

Theatre design often relies on a physical to physical process that relies on tangible design information being passed to production and technical departments directly via physical methods; plans, models, verbal language and body language (Pavelka & Chitty, 2015). When digital technologies are introduced into this process it is

[1]There is no contemporary definition of AR/MR/VR which all industries and businesses can agree to. For the purposes of this study, the term AR has been used although the owners of the technology (Microsoft and Magic Leap) would prefer the term MR. This is because for it to be a truly "mixed" reality experience, the content would need to interact with the real world and have an awareness of the environment. This project has used static holograms that are unaware of their environment except to be locked in place, and therefore is Augmented Reality (AR) has been adopted as the term.

primarily for the purposes of transferring physical information in a digital format, such as digital 2D cad drawings or photo scans of reference artwork (Carver & White, 2003). Whilst these processes are in themselves digital they are only extensions of physical media which has been replicated and passed on in a format that is more convenient to the users or for the benefit of replicating data where multiple copies benefit a large production team. (Mitchell, 2009, 79)

The theatrical experience is fundamentally a physical, embodied art and no matter how high the fidelity and detail of a digital pre-visualisation model, without people, it loses its sense of scale and relationship with the story. Even when we believe we are presenting digital information as purely digital, it still exists on a physical medium as it must be processed by a screen, or transmitted through copper cables or presented as sound through physical speakers or light through a physical lens (Hayles, 1999). Designing with pre-visualisation systems currently relies on 3d representations of a production viewed on a screen (Carver & White, 2003), but by using AR we are able to bring creatives and performers into the same visualisations as a full-scale hologram, experiencing it much more closely to how they would in the real world.

By putting emphasis on the human beings in theatre pre-visualisation, we are able to promote the use of this technology with directors and choreographers who sometimes resist the idea of doing any creative work in a digital, virtual environment. Evidence of this is given by Mitchell (2009) and Pavelka and Chitty (2015) who both talk about the reliance on physical model boxes over digital as a way to discuss and iterate a design. A reason for this is given by Thurow (2017) who suggests that the complex user interfaces of digital visualisation tools are time-consuming to learn and therefore the artists themselves prefer to use analogue tools which are more intuitive.

The research I describe here, which combines work conducted in professional producing theatres with the support of several academic institutes, is exploring and experimenting with the role that advanced visualisation can play in the theatrical design process. Practical case studies are being developed to test and develop approaches to using full-scale immersive media to create collaborative and dynamic design environments.

This paper considers the complex human aspect of this particular research: how to engage creatives in the visualisation process using immersive media, and how can we bring human beings into the visualisation itself to provide real-world context.

Questions this paper will address are:

- Are creative teams more likely to engage in digital visualisation processes if the medium for viewing it is immersive? If so, why?
- Is a digital visualisation of a scenic design more useful to a creative team if it includes digital representations of human performers, digitised through motion capture or tracking systems?
- To what extent or to what degree of detail provides the optimum environment to induce or support creativity and new design iterations?
- How does holographic scenography, augmented over live performers in rehearsal, induce or support creativity and new design iterations?

Technology which is designed to work with the human body's physiology are considered more realistic (Rubin, 2018) and natural for the user. For instance, the human eye has a natural parallax which, when converged and merged by our optic nerves and processed by the brains visual processing, provides our sense of perspective and allows us to judge distance (Kade, Lindell, Ürey, & Özcan, 2016). Breaking the rules of perspective and realism gives rise to the "uncanny valley" effect where digital becomes unbelievable because it falls short of the human experience of what is considered "real" (Theodore, 2004).

Stereoscopic experiences (commonly known as 3D in TV and film) have taken advantage of this property of human physiology to create a visual effect that feels more natural and has allowed film producers to exploit and in some cases over-exploit, this visual indication of realism to enhance their films (Baños et al., 2008). This technique has been demonstrated in a live performance by Mark Reaney (Thurow, 2017) who used stereoscopic rear-projection to create productions where the content appeared to float above the stage in a believable way.

Whilst this particular technology has been inconsistently brought back to the market, research and analyses in this field have provided makers of immersive media techniques to create believable and realistic visual content that exploits the human bodies physical and emotional systems.

The very best of immersive content doesn't just rely on high-quality technology to deliver the experience, it relies on creative content that responds to the human being's natural emotional and physical triggers; tension, predictable patterns, directionality, coordinated visual and audio stimulus and engaging storytelling (Catmull & Wallace, 2014). Creating virtual environments whether for storytelling or for design can benefit from research into human physiology and emotion that has been developed since humans first told stories around a campfire and which later developed into live performances in a seated arena, to theatre as we know it today and eventually to mediums such as film, tv and computer games.

For immersive media to support design visualisation, it needs to be engaging and useful enough for creatives to want to use it and keep using it (Rubin, 2018; Thurow, 2017). By exploiting the attributes that immerse humans in other formats of digital content, we can create better immersive environments for design development.

The digitisation of human performance, either as digital doubles which replace a performer in a film, or the recording of movement data via motion capture sensors is common today in film and game production (Delbridge, 2016), but not in pre-visualisation.

Research conducted by Kade et al. (2016) demonstrates the effect on the performer of wearing immersive headsets whilst having their performance captured. It demonstrates the positive effect in developing a performance, by allowing the director to engage with the performer to help them develop their role. This is combined in the overall design by seeing the overall effect of the digital performance overlaid with digital scenography. This research supports the idea that digital representations of all creative elements improve design iteration and collaboration. Whilst Kade's research didn't experiment with the director experiencing the full visualisation using immersive media, it did demonstrate how immersive media supported the performers' engagement in the visualisation. This supports the hypothesis that immersive media is a more engaging medium for creative teams than other digital formats.

Creating a fully digital, visualised version of a production, and augmenting it over a rehearsal for the creative team to view will provide evidence to support or deny the role of visualisation in theatrical production design. Introducing the human factor to the visualisation is, I want to argue, key to the success of visualisation in mainstream theatre. I also believe that theatre productions themselves will be more successful if the producing team and creatives engage with a visualisation experience.

Bringing digital humans into the visualisation provides an understanding of the relationship and scale of what is considered the most important part of a production; the performer. In order to justify the endeavour of digitising an entire production, it is necessary that the creative team engage with it regularly, and this is why researching how and why a human being engages with digital visualisations is so important because without their engagement the benefits of digital visualisation are unlikely to be gained.

2 Methodology

This research requires an understanding of how the design process is affected by the use of AR holographic visualisations. Whilst simulated and controlled test environments provide quantitative data which can be tracked, the qualitative information created from working on a professional, real-world production environment is more useful in the context of design where the constraints and conditions of real-world producing have an impact on the process and product.

There needs to be a fine balance between the research objectives and maintaining the integrity of the design process since the participants are involved in the project in a professional design capacity and not to facilitate the research.

The experiment is being presented as a tool to assist in the production and to further their aims—with the caveat that they understand there will be research collected during this process and questions or interviews during or after which may be published.

2.1 The Case Study

Due to the nature of theatrical intellectual property, it is customary to credit the artists and their role, and not to anonymise them once permission has been granted.

The production which contributed to the research for this experiment is "*Rejoicing At Her Wondrous Vulva, The Young Girl Applauded Herself*", at Ovalhouse Theatre in Oval, London. The people who contributed to the experiment were; the writer and performer, Bella Heesom, Direction by Donnacadh O'Briain and design by Elizabeth

Harper. The Artistic Director for Ovalhouse is Owen Calvert-Lyons. For brevity, the production shall be referred to as Wondrous Vulva.

An initial study with Calvert-Lyons on an earlier production was necessary to give both the venue and the research team the confidence to explore other productions that it could be exploited on. In this case, the production design was relatively simple and the process of working in AR was limited to Calvert-Lyons as the production's director. He spent 30 min exploring the scenic design for his production "*Random Selfies* " using AR with the Microsoft Hololens. The experience was effective because it confirmed for him that the placement of the staging was correct and created the same stage environment as he had seen in mock-ups of the real production.

This exercise served two purposes: firstly to validate the process for Calvert-Lyons before proceeding to work with another production team and secondly to identify the type of production that would find the most use for it.

It went without saying that productions without scenery were not going to be useful, as the purpose of the experience was to see a hologram of the scenery. He also wanted to find a production that had a production team with an open mind, who would be open to the idea of experimental technologies and who had a process that was fluid and flexible to allow the integration of pre-visualisation.

The team for *Wondrous Vulva* were chosen for precisely this reason and were open and accommodating in allowing experimental research into their design process. They needed to be familiarised with the technology before they were able to use it appropriately and so a demonstration was prepared during a design meeting to see an example hologram. This created a precedent for expectations and prior research has shown that many are disappointed by the narrow field of view of the Hololens, particularly if they have had any experience of VR where the view is much wider [90° instead of the Hololens 35° (Lang, 2019)].

In the stages leading up to the pre-visualisation workshop, the research team were asked to join the production team and worked as would be expected of a professional visualiser and not as a researcher. This meant that there were opportunities to share the designs of the production and provide continual feedback on the development of the digital 3d model to ensure it was being built correctly.

2.2 Design Challenges

There were a number of challenges developing a 3d model for this production. The main limitation is the processing and graphics power of the Hololens which isn't able to sustain very complex models or geometry (Garon, Boulet, Doironz, Beaulieu, & Lalonde, 2016). One of the most visible (and therefore a priority for pre-visualisation) scenic elements, was the hanging wisteria which fell at different heights from a grid across the entire ceiling. There were known challenges to the design team from working with this element, from obscuring the lighting rig, creating a potential fire hazard to the very practical problem of sourcing and/or manufacturing all the wisteria on a very small budget.

The challenge of working with wisteria on this project is that it is a very dense plant with many folds and layers of petals which, if modelled correctly in digital 3d, would take up far more polygons than the system could handle (Liu, Dong, Zhang, & Saddik, 2018). The detailed modelling needed to be compromised to meet these requirements, and the games industry has mastered techniques to make detailed 3d elements look complex when in fact they have been optimised to be as efficient as possible (Gahan, 2011).

For this particular element, an image of wisteria provided by the designer was converted into an alpha mask (a layer inside a texture to determine transparency) which allows the coloured sections to be appear solid and the background of the image to become transparent. When applied to a simple plane (using only two polygons) this image can appear very complex but is actually the smallest geometry size it is possible to create.

The downside of this technique is that a textured plane in a game is designed to follow you (the character) around so that your point of view relative to it always remains perpendicular. On a screen this is not so jarring but in an immersive, full scale model, the effect of planes moving to follow you breaks the sense of immersion and reality takes over. It also creates quite a technical challenge as this type of technique requires advanced programming which is a resource the research team didn't have available to them.

Another challenge is the representation of dark objects in the hologram. In a device that uses light to produce objects, black becomes the equivalent of being transparent and displays no content. On a screen, this would simply be represented by black pixels but in a holographic experience, the absence of light means the absence of content and thus reveals the real-world behind. Whilst this may seem obvious, it does create a lot of confusion to the design team who are expecting to see an element of scenery in a certain place but fail to because it isn't being drawn in the visualisation. Seeing other scenery behind it, in these circumstances, can further break the sense of illusion.

2.3 Technical Challenges

There are prescribed rules for the ideal environment for the use of the Hololens and "inside out tracking" devices like it (Brown, McCulloch, Zeller, & Bray, 2019), and theatre is the worst case for nearly all of them. Low lighting, dark surfaces, large empty spaces where the nearest trackable surface may be more than five meters away are all examples of typical theatres and also examples of environments considered to be poor for Hololens performance. However, despite these limitations in the studio theatre at Ovalhouse, the device's tracking (its ability to know where it is relative to its origin) worked very well. This was because there was a lot of scenery on stage for another production—something that would be considered negative in any other form of design meeting but is an advantage for Hololens.

The narrow field of view of the Hololens (35°) is an impediment for when you are “inside” the holographic experience and want to feel the full sense of immersion. However, at a distance back, for instance, in the middle of the seating bank, enough of the scenery was visible to still be able to make informed choices.

The battery life of the Hololens meant that the team were not going to be able to have more than one hour of time working with the experience, and it was best to plan for the worst case which is forty minutes. If a design team were in the middle of a fully collaborative discussion due to the use of the Hololens, it wouldn’t necessarily reverse its effectiveness in creating better design, but it would fail to continue to achieve its primary function which is to encourage collaborative communication.

3 Results

3.1 Elizabeth Harper—Designer

When Harper first put the Hololens on, there was a moment of normalising, where she was impressed with the visual picture. It wasn’t clear whether she was pleased with her own design in the space or the Hololens experience when she said: “It looks pretty damn lovely”. Because she had experienced the familiarisation demonstration conducted several weeks before, it is more likely that her exclamation was due to her impressions of her own scenography in the space, something which reinforced how fast she normalised to the experience and began to perform in her function as the designer instead of an observer of something new, which is further evidence that she adjusted to the technology very quickly.

It was not unexpected for Harper to be able to normalise so quickly, but her rapid transition from “Hololens experiencer” to “designer using pre-visualisation” was possibly due to the fact the key elements of the experience were not unfamiliar to her. Besides the technology, which is almost completely new to her, the process, in its separate parts, is very familiar. For instance, as a theatre designer, she is used to thinking about the scenery through a model box (a scale model of the scenery) which has textures and finishes that may represent the finished product whilst not being entirely accurate. As a designer, she is used to experiencing these less-than-perfect finishes which she could see in the Hololens. Designers are also used to walking into a venue after or during the scenery being constructed and having an instant opinion about scale, position, angles etc. These two latent experience traits of designers may explain why Harper was able to so quickly transition between experiencer and professional designer.

The subsequent moments with the Hololens were in-line with the typical reactions of a designer (Pavelka & Chitty, 2015) and was confirmed by Harper who said that she was able to discuss the design with her collaborators in the same way as she would have had the real scenery been there.

The nature of the hardware limitations and design constraints (as discussed in Sects. 3.2 and 3.3) were noticeable to Harper who, whilst understanding of the reasons, had to process the lower fidelity representations of her design using her own imagination. This was easier for her who understood her design so well, but when communicating with her collaborators it was harder as they didn't have the same "mind's eye" as her. It is supposedly a more complex task of re-imagining something you can see in front of you into something else and is a distraction when you are attempting a design conversation about something visual.

3.2 Donncadh O'Briain—Director

As an experienced director, O'Briain has a method he applies to his directorial process that he knows works for him. He has used visualisation in his past productions, but principally as physical, scale model boxes. He has however on two occasions used 3d digital visualisation on a screen and likened his experiences of these with the experience he had with AR using the Hololens.

The main benefit of the Hololens experience over the screen for him was the spatial awareness where he could judge the relationship between the scenery and the space it was in. The distance from the audience to the performance area and the position of the actors relative to the scenic elements. These are things that are best perceived when standing inside the actual scenery at full scale and getting the truest sense of feel for the show. A full-scale hologram, for him, was almost as good for conveying these feelings—although it was lacking in other areas as a piece of technology (field of view).

His main conclusion was that it was able to provide more "colour and texture" to the preparation process which helped inform his directorial process in the rehearsals. O'Briain's directorial style is to act on impulse and react to what he is seeing in the space, using pure creativity and inspiration to throw ideas into the process to be tested and workshopped. However, it would be wrong to assume that impulsiveness means un-preparedness. The impulses are built on a foundation of strong preparation that comes from research of the set design, the writing, the contextual issues of the piece and discussions with the rest of the creative team. Of these four areas, three of them can be undertaken in full because they require no separate medium to act as a vehicle to aid his process. This is not the case with the set design which is never fully realised until seen in the space it will be performed in. Holographic visualisation is the closest O'Brain could get to the final product until after the performance workshops and rehearsals had finished.

As a result of the AR experience, decisions were made to move the entire production further upstage by several meters—a decision that would have cost several hours if undertaken once the real scenery was in position and would have had a huge impact on other departments such as lighting. It also led to the creation of "mounds" of earth covered in grass which were used for moments of the performance and were conceived or at least confirmed, as part of the pre-visualisation experience using the Hololens.

Another element of the scenic design which was changed, indirectly, as a result of the AR experience was the chair which was replaced for a swing in the final production. The decision to remove the chair wasn't made until viewing it through the Hololens, but the idea to remove it occurred earlier when O'Briain saw the design in the physical model box. Had the AR visualisation been used before the model box, the same idea would have come which suggests that AR visualisation is as effective as a model box for conveying the scenic design, at least according to O'Brain's account of the process.

What AR contributed to O'Brain's decision-making regarding the chair was more than simply confirmation; it also gave an opportunity to discuss the issue with Harper whilst both were wearing a Hololens. The shared visualisation experience gave both a common visual language where there were no assumptions or misunderstandings about the qualities of the design. Cutting a design element is a sensitive matter, as it can be seen by the designer as a criticism of her or his work by the director. The dialogue between O'Briain and Harper was delicate, as might be expected of two professionals used to suggesting and receiving criticisms of each other's work. A discussion like this is never easy but is—I would suggest—easier when the team are in the space and in the presence of the final product which grounds the discussion around something concrete. Having the shared AR experience provided such an opportunity and allowed O'Briain to delicately present his concerns and offer solutions to Harper in a way that wasn't offensive and opened the dialogue up as an opportunity for improving the design. In this way, shared AR experiences support communication between team members and allowed a conversation to happen before the money had been spent on an expensive chair—something which O'Briain expressed to Harper at the time of the conversation as a reason for bringing it up at all.

3.3 Bella Heesom—Writer/Performer

Heesom was experiencing AR as both writer and performer and it isn't easy to distinguish which of these roles she was inhabiting when she was first using the Hololens. She made reference to the water trough at the back, which as a performer she needed to bathe in, but she made a comment about the AR experience giving her ideas what to write. She was very interested in the position of the water trough and her point of view showed several times she looked from the water to the audience which isn't far away. This is possibly because at the moment in the show when she is near the water, she joins her fellow performer in removing all of her clothes to get in to. Her interest in the relative position of the water to the audience may have been to reinforce the moment in her mind, to provide confidence for what must be a very vulnerable undertaking—even for a professional.

A by-product of Heesom engaging with the scenery in situ using the Hololens, is that the other Hololens being shared by the rest of the creative team were able to witness a performer using the space and the relationship between her and the scenic elements. Speculatively, I would suggest it may have influenced some thinking around the blocking (positioning of the performers on stage) and is a possible area of further research to develop.

4 Conclusions

The majority of design decisions were made much earlier in the process and there were not many changes that were needed at the point that the AR system was used. There were however a few examples of design changes and confirmations that arose from the AR experience that could be pointed to, such as the mounds, the chair and the re-positioning of the set further upstage. Calvert-Lyons claims this saved three hours of technical time in itself which is valuable time both as a cost (due to the staff and equipment costs in that time) and would result in the limited design time in the space being taken up with changes that could have been resolved in advance.

It did provide confirmation of the scenic design, and the fact that there were not many subsequent changes was largely due to the thoroughness of the design process up to that point.

Providing confidence has subliminal effects on many other parts of the process, and these effects spread to influence other elements of the process in positive ways. For instance, the AR visualisation had an effect on the way that O'Briain directed his performers. By securing his own understanding of the set he was able to have creative ideas that may not have come without them. It is not possible to confirm if these ideas would have happened without the AR experience, but the opinion of O'Briain was that it had a positive effect on his process, so much so that he would want to use it again.

There were limitations around the field of view of the Hololens which limited the immersion of the experience. In future projects, I would try to utilise 2nd generation Hololens or Magic Leap technology which has a much wider field of view.

The aim of this research was to identify the effect of using AR on a human-centric process—creativity. It succeeded in establishing itself as part of the creative process, supporting the human minds-eye by making visible that which is held in imagination. Design requires three things to develop: creativity, collaboration and communication (Simpson, 2018). The use of AR in this system provides the opportunity for all three of these a lot more than it would without, without detracting from the process. It hasn't become a step change in the design process, which in itself is no bad thing if we want this technology to be easily accommodated into an existing system, and it has definitely provided benefit to the design team in several ways as discussed. With more devices, additional tools and interfaces, such as a UI for the designer and director to use to manipulate and interact with the digital model, it could become an accepted part of the theatre design process.

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The Use of VR in Journalism: Current Research and Future Opportunities

Irina Tribusean

Abstract Virtual reality (VR) is more and more used in journalism since 2015 and research is trying to keep the pace. This paper gives an overview of the existing academic research on the topic. First, key concepts are defined, as some terms, such as immersion and presence, are used in various fields with slightly different meaning. Second, the existing research on the use of VR is presented. Research on production mainly analyses challenges of the new technology and ethical issues, while studies on audience are rather empirical, looking at the users' reactions to the new medium, compared to the classical TV and print. Finally, the state-of-the art is discussed and some research gaps are pointed out, followed by recommendations for further research.

Keywords Virtual reality · VR · VR journalism · Immersive journalism · 360° video · CGI

1 Introduction

With each step in the evolution of media technologies—photography, television, interactive, immersive and social digital media, and finally virtual reality (VR)—the viewer got closer to the experience of others, now even having the chance to be an active participant instead of a passive witness. This is possible due to the defining concepts of VR, mainly immersion and presence, offering a "qualitatively different media experience than other forms of visual representation" (Aronson-Rath, Milward, Owen, & Pitt, 2015, p. 21).

The concept of VR is not new and its potential for journalistic use was discussed already in 1995 by Biocca and Levy, who mentioned that at that point the promise of VR was "still a vision" (Biocca & Levy, 1995, p. 13) and compared its development with that of the radio and television. But unlike those two, VR has an "incredible pace of change" (Watson, 2017, p. 8). Nonny de la Peña first explored VR for immersive

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journalism in 2010, then “New York Times” was the first big media company to launch a VR app and distribute Google Cardboard to its audience in 2015. Other media institutions and production studios, such as “Wall Street Journal”, “USA Today”, CNN, BBC, the “Guardian”, RYOT, “Vice”, “The Verge” and many others, followed their example during the past several years (Hardee & McMahan, 2017; Jones, 2017; Sirkkunen, Väätäjä, Uskali, & Rezaei, 2016; Watson, 2017). One of the reasons for this phenomenon is that VR by definition offers a sense of “being there”, fulfilling the “oldest dream of journalists”—to give audiences the perception of “being present at distant, newsworthy locations and events” (Biocca & Levy, 1995, p. 138). Using VR, journalists can give their audience the impression of being exactly where the event happened, which makes it “an innovation never provided in the history of journalism” (Moreira Flores, 2017, p. 167).

The wider use of VR in journalism generated discussions on a number of issues, both in the academia and in the industry. Among these issues are the technological challenges related to production and distribution of the content (Aronson-Rath et al., 2015; Doyle, Gelman, & Gill, 2016; Watson, 2017); ethical aspects (Kool, 2016; Pérez Seijo, 2017); the role of the journalist and the structure of the newsroom, journalistic content, new forms and genres (Domínguez, 2017; Hardee, 2016; Hardee & McMahan, 2017; McRoberts, 2017); and last but not least challenges related to audience expectations and reception (Brautović, John, & Potrebica, 2017; Shin & Biocca, 2017). Still, this is only an initial stage and more research needs to be done (Sirkkunen et al., 2016; Watson, 2017), in order to answer the open questions and fill the existing research gaps, some of which will be discussed at the end of this paper.

2 Defining Key Concepts

VR and concepts related to it are rooted in computer science, but have been largely used in various fields lately. Definitions often differ from field to field, so it is necessary to clarify the concepts relevant for journalism and communication.

Since the 90s, VR was mainly defined as an environment or medium, with a strong focus on technology. Here are two recent examples: “**virtual reality** is defined to be a computer-generated digital environment that can be experienced and interacted with as if that environment were real.” (Jerald, 2016, p. 9) and “**Virtual reality**: a medium composed of interactive computer simulations that sense the *participant*’s position and actions and replace or augment the feedback to one or more senses, giving the feeling of being mentally immersed or present in the simulation (a virtual world).” (Sherman & Craig, 2019, p. 16) (original emphasis kept). This kind of definitions makes sense for the producers, but fail to offer a suitable framework for the analysis of the media contents and the effects on the consumer using VR products (Steuer, 1995). Therefore, Steuer (1995) defined VR “as a real or simulated environment in which a perceiver experiences telepresence” (p. 37). Even though this definition focuses on a key element of VR—telepresence[1] ["the mediated perception of an environment" (Steuer, 1995, p. 36)], and it is broad enough to include any kind of media experiences, it seems to ignore other two key elements of VR, namely immersion and interactivity. Therefore, the following definition fits better as a conceptual framework for communication and journalism research: "Virtual reality (VR) is an *immersive* media experience that replicates either a real or imagined environment and allows users to *interact* with this world in ways that feel *as if they are there*." (Aronson-Rath et al., 2015, p. 12) (emphasis added by the author).

The term immersion is not new and it has been used in a wider media context, including journalism (de la Peña et al., 2010), referring rather to a mental state (mental immersion) than to a physical one (physical immersion) (Sherman & Craig, 2019). Traditionally, immersion was understood as a research technique, based on the idea that "the journalist needs to live the situation to make the readers feel they are there" (Domínguez, 2017, p. 2). The term is also linked to the New Journalism movement, also known as literary journalism, where the first person narrative is used (Jones, 2017), in order to ease the immersion process for the reader. This corresponds to diegesis—an immersion technique, "where a detailed written description can enable the reader to establish a mental picture of a place into which they become transported" (McRoberts, 2017, p. 6). Mimesis, on the other hand, is showing instead of telling, leads to a faster immersion and fits well to the characteristics of VR (McRoberts, 2017).

Nevertheless, "it remains unclear as to what immersion means" (Shin & Biocca, 2017, p. 2) and its meaning often overlaps with that of presence (Sherman & Craig, 2019). In the context of VR, immersion usually refers to the technical capability of a system to deliver "an inclusive, extensive, surrounding and vivid illusion to the senses of a human participant" (Slater & Wilbur, 1997, p. 3). In other words, an immersive technology can shut out the physical reality, replacing it with a vivid panoramic virtual reality. According to Slater and Wilbur (1997), immersion requires a virtual body, also known as avatar in the newer literature (de la Peña et al., 2010; Slater, 2009). A successful immersion in VR journalism can be achieved with an appropriate combination of media content (narrative immersion) and media form (technical immersion) (McRoberts, 2017; Pérez Seijo, 2017).

Presence rather refers to the user (Jerald, 2016) and "is a state of consciousness, the (psychological) sense of being in the virtual environment" (Slater & Wilbur, 1997, p. 606); a "sense of being there" (Slater, 2009, p. 3551). Presence is a product of place illusion (PI), defined as the feeling of "being there" despite the knowledge of being in another place, and plausibility (Psi), defined as the illusion that what is happening is real, despite the knowledge that it is not (Slater, 2009; Slater & Sanchez-Vives, 2016). For media content, Psi is specifically important (de la Peña et al., 2010), as it relates to the credibility of the related events. This feature of VR to provide the sense of presence (PI and Psi) distinguishes it from all other types of media (Slater & Sanchez-Vives, 2016).

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[1]Following the example of Fraustino, Lee, Lee, and Ahn (2018), this paper will use the term "presence" to refer to both spatial presence and telepresence.

Previous research shows that various technical aspects of immersion (stereoscopy, field of regard and view, display type, etc.) affect presence (Hardee & McMahan, 2017; Aronson-Rath et al., 2015). Another element to enhance presence is interactivity—"the extent to which a user can create and modify the form and content of objects" in the virtual environment (Slater & Wilbur, 1997, p. 615). Is it associated with the ability to explore the virtual environment and manipulate the object as in the real life (McRoberts, 2017). Interactivity in virtual environments is similar to narrative agency, which implies involving the user in the construction of the reality by giving him/her control over the structure of the content or the scenario in the virtual environment (McRoberts, 2017).

Both in the media and in the research community, no difference is made between computer-based (Computer Generated Imagery—CGI) VR and 360° video (Mabrook & Singer, 2019; Slater & Sanchez-Vives, 2016; Watson, 2017), even though these are two different things (Pacheco, 2017), first of all, on a technical level. The Augmented Reality/Virtual Reality working group of the Consumer Technology Group define, at the Consumer Electronics Show in 2017, VR as "creating a digital environment that replaces the user's real world environment" and 360° video as video "that allows the user to look in every direction around them" (Enders Analysis 2017, as quoted in Watson, 2017, p. 9). One main difference between 360° video and CGI is the allowed level of interactivity, even though some authors argue that being able to decide what to look at and where to focus in a full 360° image or environment also counts as interactivity (McRoberts, 2017). This is still considerably less interactive than being able to move through the scene and look at an object from a different angle, which is by definition not possible with a 360° video, but can be implemented in a computer-based VR experience (Slater & Sanchez-Vives, 2016). Despite the fact that interactivity influences presence, the distinction will be ignored and following the general trend, the term VR will be further used to refer to both 360° video and CGI.

Biocca and Levy (1995) were the first to discuss the use of immersive technologies in journalism and Columbia University's Center for New Media first tried to implement them in 1997 (Hardee & McMahan, 2017). The technological development led to a wide use of VR in journalism and, subsequently, to a shift in the definition of immersive journalism, also called VR journalism. The recent academic literature (Brautović et al., 2017; Hardee, 2016; Hardee & McMahan, 2017; Jones, 2017; Shin & Biocca, 2017; Sirkkunen et al., 2016) adopts the following definition: immersive journalism is "the production of news in a form in which people can gain first-person experiences of the events or situation described in news stories" (de la Peña et al., 2010, p. 291). Slater and Sanchez-Vives (2016, p. 31) note that "it is not the journalism that is immersive, but the presentation of its results through immersive media". The aim is not to just present the facts and events, but the opportunity to experience them (de la Peña et al., 2010; Slater & Sanchez-Vives, 2016).

It is still not clear how VR changes journalism as we know it and the role of the journalist still needs to be reassessed under the new circumstances (Aronson-Rath et al., 2015). Until then, we can build upon the assumption that "immersive journalism is above all else journalism" (Baía Reis & Coelho, 2018, p. 7) and use the existing theories, principles and values of journalism, adjusting them to the new medium. The following definition of journalism provides the necessary conceptual framework for the analysis of immersive journalism and will be adopted for this paper: “Journalism comprises the activities involved in an independent pursuit of accurate information about current or recent events and its original presentation for public edification” (Shapiro, 2014, p. 561). For an understanding of what journalism is, it is useful to look at its social functions (or roles) and values. From a normative perspective, McQuail (2010) names the social functions of journalism in a democratic society: information, correlation, continuity, entertainment and mobilization. There is no exact correspondence between functions and content form (genre), as the functions can overlap and the same content can fulfil several functions at the same time (McQuail, 2010). Further, Deuze (2005) summarizes the five ideal-typical values of journalism: public service, objectivity, autonomy, immediacy and ethics.

How journalists themselves perceive their functions have been an object for research in various context. Some of the most recent studies show, for example, that for American journalists the most important functions are to investigate government claims, to provide analysis of problems and to discuss national and international policy (Willnat, Weaver, & Wilhoit, 2019, p. 15). These overlap to some extent with the opinion of German journalists, who think that their most important roles are to report things as they are, to provide analysis of current affairs and to be a detached observer (Hanitzsch, Steindl, & Lauerer, 2016, p. 2).

3 Literature Review

The existing research related to VR is as various as its application, from computer science, military, medicine and health, to games, marketing, tourism, education, media and, finally, journalism (Slater & Sanchez-Vives, 2016). While some of the research in other fields can partially be relevant for VR journalism (e.g. related to immersion, presence and users’ reactions to the medium), it will be mostly left out for space efficiency reasons.

Research on the use of VR in journalism is still in its infancy and focuses mainly on two aspects: production and user experience (Sirkkunen et al., 2016). The former includes studies related to reasons and motivations for using VR in journalistic production, technical issues and challenges, content and ethics, while the latter refers to various user reactions and media effects, such as news recall, perceived credibility, and cognition, among others.

3.1 Research on Production of VR Journalism

Some of the first questions regarding the use of VR in journalism are why and what is the benefit compared to other media? There is still no systematic research dedicated to these questions, but several studies attempt to answer them, using an explorative approach. The journalistic curiosity, the wish to experiment with the new technology and be among the first using this innovation have been strong motivators (Watson, 2017). Using VR means keeping up with the audience's expectations and even attracting new audiences (e.g. gamers, who used the technology before) (Aronson-Rath et al., 2015; Doyle et al., 2016). The new immersive technology should help the user better understand the stories; it should remove bias and let the audience reach its own conclusions (Aronson-Rath et al., 2015). VR can make the audience overcome borders and get to places otherwise not accessible, such as war zones or past events (Anderson, 2017; Doyle et al., 2016; Marconi & Nakagawa, 2017; Sánchez Laws & Utne, 2019; Staschen, 2017). Marcelle Hopkins from "New York Times" explains it best: "For us in journalism, it [VR] is a medium that allows us to take our audience to places, to allow, to help them to experience something, to absorb sights and sounds of a particular place unedited" (as cited in Watson, 2017, p. 21). Putting the viewer in the middle of the event can enhance some of the above-mentioned core journalistic values such as impartiality, objectivity, transparency, and, as a result, credibility (de la Peña et al., 2010; Staschen, 2017).

Empathy has become a key-word in the context of VR journalism, especially after Chris Milk described VR as the "ultimate empathy machine" (Watson, 2017, p. 21). Nevertheless, it is questionable whether empathy is of crucial importance in journalism (Watson, 2017). Moreover, Hassan (2019) critiques the whole concept of empathy generated by digital media, arguing that the "news event cannot respond to us in a cybernetic way, in a truly 'I and thou' interaction, which is the only context where the generation of empathy may have some possibility of success in the journalistic sense claimed by New York Times, The United Nations, VICE news and others" (p. 13).

The production of VR journalism requires, besides investments in hardware and software, additional technical knowledge and skills. Given the novelty and the fast development of the technology, there is still a lack of conventions and guidelines for producing VR journalism (Benítez de Gracia & Herrera Damas, 2019). As a result, there is much experimental work, learning by doing and multidisciplinary teams, where journalists work together with designers, motion graphic producers and software developers (Aronson-Rath et al., 2015; Doyle et al., 2016; Marconi & Nakagawa, 2017; Watson, 2017). Even though fundamental components of narrative, such as characters, actions, emotions, locations and causality remain the same in VR as in the traditional television (Aronson-Rath et al., 2015), VR allows user to experience the story at their own pace, so journalists still need to discover how to build the best narrative for the new medium (Doyle et al., 2016). On the other hand, it is still not clear what kind of content (topic, genre) is most suitable for 360° video or computer-based VR and where it makes more sense to stick with the traditional media (Watson, 2017). Most of the literature on the VR journalism makes no difference between journalistic genres and uses the term "news" to refer to journalistic products in general (de la Peña et al., 2010; Domínguez, 2017; Hardee, 2016; Pérez Seijo, 2017; Shin & Biocca, 2017; Slater & Sanchez-Vives, 2016). News as a genre hardly fit with the new VR technology due to time constraints: news is fast, while qualitative VR production needs more time than any other form and medium. Hardee and McMahan (2017) developed a framework for the immersion-journalism intersection (FIJI), defining four types of immersive journalism: 360° breaking news video, mobile immersive public service, computer generated-based immersive investigation and immersive explanatory reports.

Besides opportunities, the VR technology brings several ethical challenges for journalists, beginning already with its basic characteristics. If we accept that the sense of presence, a basic element of VR, occurs when "the mind tricks the body into feeling that it is somewhere else" (Jones & Dawkins, 2018, p. 186), is it even fair to use it in journalism, where core values are realism and transparency (Hardee, 2016; Pérez Seijo, 2017)? It is important to define the role of the journalist in this new context, as this medium, due to its capabilities, implies high manipulation and propaganda risks (Kool, 2016; Slater & Sanchez-Vives, 2016). Kool (2016) questions the intentions behind some productions labelled VR journalism, on the example of "Clouds over Sidra": "one has to consider how much of the "empathy" it garners is truly a marketing ploy for the distribution of the Samsung headset, the diplomacy of the UN, or the attention of Vrse"[2] (Kool, 2016, p. 7). Furthermore, when using the technology to put the audience in the middle of the event, the journalists should assume the responsibility of the consequences (e.g. psychological impact of war and suffering) or at least share this responsibility with the users (Doyle et al., 2016; Sánchez Laws & Utne, 2019).

Labelling 360° video as VR can be seen as disinformation and thus unethical, due to the limited allowed interactivity (Sánchez Laws & Utne, 2019). In the context of core journalistic values, the 360° video can have both a positive and a negative impact. Journalists believe that this format provides more information and transparency, thus increasing accuracy. However, the ability to decide where to look and what to focus on can make users miss elements of the story, which results in less accuracy (Aitamurto, 2018) and truthfulness (Mabrook & Singer, 2019). It is still not clear how to deal with manipulations on 360° video, the discussion ranging between showing original video as a journalistic rule and necessary manipulation for better accuracy (Aitamurto, 2018). This is not a problem anymore in the case of computer-based VR, where the image is constructed and the user's trust is rather based on the trust in the journalist than on the lack of manipulation (Sánchez Laws & Utne, 2019). However, it is questionable whether recreating a 3D image or object to be used in the VR environment is ethical, taken into account that not all information is available in the 2D version and the missing parts would be recreated based on assumptions (Pérez Seijo, 2017). On the other hand, Slater and Sanchez-Vives (2016) argue that there is no journalistic reporting without a certain degree of transformation, as it is not possible to depict every details of the reality. The opinions about the presence of the journalist in the 360° video are also contradictory: the absence symbolizes

[2] "Clouds over Sidra" is a short documentary about Syrian refugees, directed by Chris Milk (founder and CEO of "Vrse", currently known as "Within") and produced by the United Nations in partnership with Samsung (Kool, 2016).

objectivity, but it also involves staging, which reduces authenticity (Aitamurto, 2018; Kool, 2016; Sánchez Laws & Utne, 2019).

Given these contradictions and open questions, further research is necessary and journalists should work together to “define ethical standards for 360° journalism” (Aitamurto, 2018, p. 15), which will distinguish journalistic VR content from other media, building trust and credibility (Sánchez Laws & Utne, 2019). Meanwhile, existing ethical standards can guide the work of VR journalists (Jones, 2017; Marconi & Nakagawa, 2017; Slater & Sanchez-Vives, 2016).

3.2 Audience Research

One of the early studies comparing the effects of VR as a medium for news with print and broadcasting elicited unexpected findings, contrary to most of the journalists' expectations. The research found “no statistically significant difference in feelings of empathy, intent to act, or attitudes towards stigmatized groups” between the VR and the other two conditions—print and broadcast (Hijazi & Cuillier, 2017, p. 16). These results might be explained by the novelty of the technology and are not confirmed by the more recent research, where users who watched a 360° video with a head-mounted display (immersive VR) experienced a stronger empathetic response compared to non-immersive formats (desktop 360° video and text). They also had a better memory for the story two weeks after the experiment (Archer & Finger, 2018). Nevertheless, it seems that “personal tendencies and the device's properties have combined effects on attitudes and experiences”, so that for people with a lower immersion tendency TV generates more empathy and embodiment than head-mounted displays (Shin & Biocca, 2017, p. 11).

In the research on media effects, a popular approach is the recall and knowledge gain (Pincus, Wojcieszak, & Boomgarden, 2017). According to the cue summation model, more cues or stimuli enhance learning and the dual coding framework shows that information delivered via different cognitive sub-systems (e.g. reading, listening, watching) is easier recalled. However, limited-capacity information processing and multiple resource models assume that information provided via more than two stimuli requires too much effort and is disturbing the knowledge gain. Narrative transportation in storytelling, corresponding to presence in VR environments, is shown to increase the knowledge gain and recall (Pincus et al., 2017). Building on these results, one could expect that the use of VR as a medium for journalistic reporting results in higher knowledge gain and recall due to higher levels of immersion and sense of presence. Contrary to expectations, watching news in a 360° video format does not affect memory and understanding in a negative way, but has a positive impact on presence, enjoyment and credibility compared to a 2D format. Furthermore, the sense of presence has an indirect positive effect on enjoyment and credibility, but not on recognition and understanding of 360° video news (Hendriks Vettehen, Wiltink, Huiskamp, Schaap, & Ketelaar, 2019). Another study yielded different results, concluding that on a long-term (five weeks after the experience), VR formats have a positive impact on story recall, in this case compared to a text version of the news (Archer & Finger, 2018). These results confirm the findings of an earlier research, where both immersive and non-immersive 360° video had a positive impact on credibility, memory and story-sharing intention among users, compared to a text with images. Furthermore, the same study showed that emotional stories have a stronger effect on generating presence than the technological factors (Sundar, Kang, & Oprean, 2017).

VR can be a good medium for increasing trustworthiness: it seems that users trust more the narrator in VR formats (both immersive and non-immersive) than the author of a text version. The trust was found to have a positive impact on immersion and emotional reaction, which in turn has a positive effect on the desire to take action (Archer & Finger, 2018).

Still, 360° videos are not as popular as non-VR videos in general and do not generate as much user engagement (liking, unliking and commenting), according to a study of the Youtube channel of the "New York Times". An interaction effect between video type and content on popularity have been found, showing that sports is the most popular topic for non-VR videos, while culture and science are the most popular for 360° video (Wang, Gu, & Suh, 2018).

One of the few studies analysing audience reactions to a computer-based VR journalism production ("We wait" from BBC) showed that responsiveness (characters looking at the user in the VR environment) had a strong positive effect on Pi and Psi, and made the users behave, think and feel as if the people were real. Additionally, embodiment (having a body in the VR environment) also had a positive, but smaller, effect. These results imply that "some minimal changes to the scenario can be positive", despite the belief that interventions in the narrative of news would alter the truthfulness and accuracy of reporting (Steed, Pan, Watson, & Slater, 2018, p. 13).

4 Discussion and Conclusion

VR, in all its forms—360° video and CGI, immersive and non-immersive—is clearly already a part of the journalistic practice. The fast technological development makes it easier to deal with production challenges and reduces costs, both for production and for visualization tools. The audience gets used to the new medium, slowly, but surely. During the past several years, there has been some new research on VR journalism, including several empirical studies on user experience (but rather quantitative and almost no qualitative, explorative). They showed the impact of the new medium on information recall and understanding, empathy and emotional response, trust and credibility, giving an insight into media effects in VR, but also generating many new questions. So the biggest unknown is still related to the audience needs, interest and reception (Sirkkunen et al., 2016; Tse et al., 2017; Watson, 2017).

Results of the published studies are sometimes contradictory (e.g. Hijazi and Cuillier (2017) vs. Archer and Finger (2018) on empathy and memory in VR video).

There are several possible reasons for that: novelty of the technology, personal characteristics of the participants (e.g. immersion tendency, previous experience with VR), variations in the used visualization tools (e.g. newer head-mounted displays might offer higher quality of immersion), and methodological challenges, among others. The findings partially support the hopes and expectations of journalists who use VR in their work, even though further systematic research is necessary to better understand these expectations.

At this stage there are only few computer-based VR productions in journalism and even less research including this kind of productions. Given the high costs needed for computer-based VR, it makes sense to use the existing productions for studies on user experience, to gain a deeper understanding on how this specific format influences the reception and whether it is worth the investment. Moreover, research directly linking the expectations of journalists with audience effects, overall rare in academia, are totally missing at this stage in the research on VR journalism.

Theory building studies, proposing new concepts, models or frameworks [e.g. FIJI framework for the analysis of immersive journalism (Hardee & McMahan, 2017)] for the study of VR journalism are also scarce. Researchers apply existing theories of journalism, media and communication, if any theory at all. However, it is still not clear to what extent these theories are valid for the VR as a communication medium, due to its major differences compared to anything we knew and used before. It is clear that VR has the capacity to induce higher levels of presence and to generate more empathy than print and 2D video formats (Sundar et al., 2017), but it also has some disadvantages, such as cybersickness (Sirkkunen et al., 2016) or Fear-of-missing-out (FOMO) (Tse et al., 2017), which are rarely addressed in the research on VR journalism.

This paper is an overview of the current state of the research in the field of VR journalism. At this stage, it is clear that VR has certain advantages compared to other media, but further theoretical and empirical research is needed for a deeper understanding of its effects on the audience. Journalists need to decide what their role in the age of VR is and to find a way to address the ethical challenges raised by this new technology. With common efforts of researchers and practitioners, it is possible to make the best out of the use of VR in journalism.

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AR and VR in Production and Manufacturing

Open Source Augmented Reality Applications for Small Manufacturing Businesses

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Abstract This paper evaluates the possibility of implementation of a low cost augmented reality application for machine maintenance in small manufacturing businesses. Here, an open source cross platform software development kit *ARToolkit* was chosen, since it offers a real time marker based tracking function. As hardware, the smart glasses R7 (ODG) and a handheld device (Samsung Galaxy S3) were considered. The application was tested on a typical milling machine used in a small size tool manufacturing company. For this purpose, its maintenance procedure was extracted from a paper-based documentation and the information provided by the workers. The AR assisted procedure was implemented using markers and an intern data server providing instructions via Wi-Fi. A maintenance demonstration was successfully performed both with a smartphone and a smart glass in the laboratory and machine hall environments.

Keywords Augmented reality · Manufacturing · Small business · Use case · Open source

1 Introduction

In small and medium size manufacturing businesses a lot of processes, such as maintenance of manufacturing machines are still documented in the hard copy form. These paper based descriptions of single process steps are often bulky. Some information is only transferred orally and require additional action from an experienced employer, which is not always possible in the daily business. In times, when a smartphone has become a mandatory accessory, it seems likely that a replacement of old fashioned maintenance books by an augmented reality (AR) application run on a mobile device

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would be a major relief and efficiency gain in a daily business (Ke, Kang, Chen, & Li, 2006). However, in a rather conservative field such is machine tool manufacturing it still remains a wishful thinking.

Still, there exist first attempts to establish AR applications in maintenance context. Since several years the automobile manufacturer Audi provides their end users with augmented reality applications for the car manuals (https://www.audi.de/de/brand/de/kundenbereich/apps/pool/audi-ekurzinfo.html [July 22, 2019]). Another example of application of AR technology is a project developing planning and maintenance of a railway line in United Kingdom (McDonnell, 2018). More applications can be found e.g. in aviation industry, plant and mechanical maintenance, mechanical maintenance and nuclear industry (Palmarini, Erkoyuncu, Roy, & Torabmostaedi, 2018). Here AR technology is mostly used for dis/assembly, repair, inspection and training. Yet it is also stated, that the existing examples of application of AR in maintenance indicate a high complexity for selecting and developing AR systems due to a high variety of hardware and development platforms. Although the first steps into the direction of introduction of AR in industrial context, it is still far from being established there (Roy, Stark, Tracht, Takata, & Mori, 2016).

In order to establish the relatively new digital technology in traditionally "analogue" companies a lot of obstacles have to be overcome. For a successful introduction of AR in this field, this technology has to be easy to use, fit in into the existing routines and keep the investment costs on the software and hardware side low.

Development of an approach of how AR can be integrated in a small manufacturing companies was one of the aim of the project founded by the research and development program "Information and Communication Technology" of Bavaria, Germany. In this paper result of this project related to augmented reality are presented. First the possibilities of a low cost implementation of an AR assisted maintenance in a small manufacturing business company are discussed. This implies as well the choice of a software development kit as well as the hardware. Subsequently, the implementation of a prototype of an AR application for a typical maintenance process is presented.

2 AR Software Development Kits

2.1 Proprietary Solutions

There exists a variety of different proprietary and free AR libraries. The offer is currently subject to fast grow and quick changes. Some comparison platform list over 70 software development kits (SDK, https://socialcompare.com/en/comparison/augmented-reality-sdks [July 22, 2019]). Some platforms have succeeded to establish their position in this field since couple of years. *Vulforia* and *Wikitude* are one of the most prominent commercial development kits examples. Such companies mostly also offer a free version for academic purposes. It however cannot be used for commercial applications. Yet the cost for the SDK is one of the key cost factors for the future application, which can be an obstacle in the early stage of AR in the small companies.

Also big software players such Google and Apple offer free yet proprietary libraries *ARCore* and *ARKit*. The drawback of these toolkits are that they only support a list of Android devices as well for Apple smartphones and the user has to be willing to agree to the terms and conditions required by those toolkits, which might be an obstacle for some companies. This disadvantage can be overcome when using open source based software.

2.2 Open Source Solutions

One of the most famous cross-platform computer vision open source toolkits is *OpenCV*. Its development started in 2000 and it is still used by millions of users (https://opencv.org/about/ [July 22, 2019]) It e.g. offers implementation of natural feature recognition and tracking. This toolkit was also tested in this project. Yet since the algorithms are not in particular optimised for augmented reality application, the performance of the toolkit was quite slow when using natural feature recognition on the chosen mobile devices.

Another open source platform offering implementation of AR features is *ARToolkit* (today also known as *ARToolkitX*), which was initially released in 1999 (https://en.wikipedia.org/wiki/ARToolKit [July 22, 2019]). It is a cross platform toolkit, which mainly offers real time tracking of markers and natural features, utilities for marker generation and calibration. Moreover, a built in optical head-mounted display support is available.

In general, it is difficult to compare the performance of SDKs, since they often focus on different aspects of AR implementation. Yet, when it comes to marker tracking capabilities, *ARToolkit* comes strong with its multiple platforms integration. This simplifies a device independent application development, if different device types such as handheld and head mounted devices need to be used in the project (Amin & Govilkar, 2015; Blanco-Novoa, Fernandez-Carames, Fraga-Lamas, & Vilar-Montesinos, 2018).

In particular comparison of marker tracking in an industrial setup the distance of the camera can be bigger when using *ARToolkit* compared to *Vulforia*. Still, the latter shows better results in poor lightning conditions (Blanco-Novoa et al., 2018). Another drawback of the *ArToolkit* compared to *Vulforia* is a slightly less stable rendering performance of 3D objects (https://www.linkedin.com/pulse/best-ar-sdk-industry-vertical-solutions-paid-open-source-prabhu?trk=prof-post [July 22, 2019]). Yet with respect to its price-performance ratio *ARToolkits* best matches the requirements of the SDK for the current work.

3 AR Hardware

AR hardware is a key factor needed to establish AR applications in manufacturing businesses. Such application require head mounted see through devices, allowing to see the "real" world and augmented projections at the same time, while the hands of the user remain free. Such devices are also known as smart glasses (Ro, Brem, & Rauschnabel, 2018).

There is a variety of smart glasses available on the marked. Syberfeldt, Danielsson, and Gustavsson (2017) gives a good overview over purchasable devices (as at year 2017). Besides an integrated see through display or a projection unit those devices are equipped with a computing unit with various sensors and communication interfaces. Depending on the requirement of the application devices with the focus e.g. on computing performance or weight are available. Examples of famous smart glasses *Google Glass* and *Microsoft HoloLens*. However, those devices were not considered in this work since they were not available on the free market at the beginning of the project.

For this project a device of the company Osterhout Design Group (ODG) model *R-7* (Fig. 1), which is initially designed for extreme workplace environments, as can be found in manufacturing, was chosen. Its key features are a dual 720p stereoscopic see-thru displays at up to 80 fps and 80% see-thru transmission. It is equipped with common communication interfaces such as Wi-Fi and Bluetooth as well as a 4k camera for optical environment detection. The computing unit is equipped with a 2.7 GHz quad core processor, 3 GB Ram, 64 GB memory and an integrated 1300 mAh Lithium-Ion battery. In comparison to other available devices the camera and the computing unit form a high performance device for implementation of real time AR application (Syberfeldt et al. 2017). Moreover, it is equipped with 9 DOF inertial motion sensors, GPS, humidity, barometric and ambient light sensors which allow further enrichment of augmented reality. The device can be controlled with integrated buttons, a Bluetooth mouse or with gestures. The major drawback this device is its relatively high weight of 170 g and high investment cost in the range of 3000 USD.

As a low cost alternative also a mobile handheld device such as smartphone or tablet can an alternative to smart glasses, when it comes to device costs and user

Fig. 1 ODG R-7 smart glasses

acceptance. Although a handheld device blocks at least one hand it still can be more intuitive for the end user than a smart glass. For this reason, the here developed AR application was also tested on a smartphone. As a test device Samsung Galaxy S3 was provided.

4 WikiProd Project

As previously mentioned the work presented in this paper is a part of the project called *WikiProd*, which aimed to investigate possibilities of implementation of a self-learning distributed and safe knowledge management system for a productive real time maintenance of manufacturing facilities (http://digitusmagazin.de/2016/02/frisch-aus-der-forschung-wiki-prototyp-fur-echtzeit-wartung/ [July 23, 2019]). One of the goals of *WikiProd* was to develop a possible prototype for digitalisation of the maintenance processes in a small manufacturing business. This included digitalisation of the documentation of the maintenance as well as digitalisation of the maintenance procedure. It implies, that the paper based maintenance instructions needed to be replaced by a digital user friendly version. The approach suggested here was to use an AR application containing maintenance steps supporting the worker in the maintenance process.

For the demonstration purpose a typical maintenance process such as changing of a cooling lubricant in a milling machine was chosen. Figure 2 shows the latter machine together with a typical documentation sheet. The information, which is necessary to perform a step-by-step maintenance, have to be partially extracted from

Fig. 2 Typical manufacturing machine together with paper based maintenance information

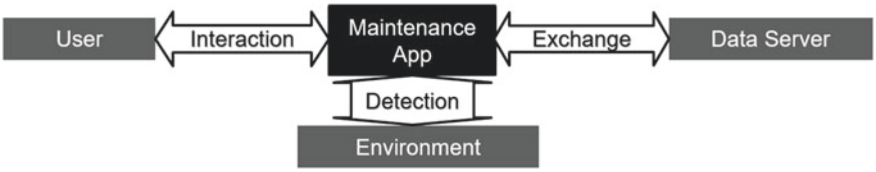

Fig. 3 Interface structure of the AR maintenance

the text and partially can only be delivered by more experienced workers. Based on this instruction, information delivered by the workers and physical dimensions of the machine itself a step by step maintenance procedure was created. This was the basis for the development of the AR maintenance assistance application.

4.1 Structure

For the AR assisted maintenance application prototype a modular structure, which should guarantee a simple access to the different parts of the application by the user, was chosen. Figure 3 illustrates the structure elements of the AR maintenance. It includes the application itself, a data server, the environment and the user. The application runs either on the mobile handheld device or on smart glasses. Its task is to link the data coming from the data server to the features of the detected environment and finally display it to the user. For the detection of the environment the device-internal camera is used. The interaction with the user is kept very simple in the prototype version. Text messages and geometric overlays are used in order to guarantee a very quick and easy. The information what components should be detected, as well as maintenance instructions themselves are stored on an external data server. Here an autonomous minicomputer, which was equipped with Wi-Fi access, was used in order not to interfere with the company's IT systems. The *BlueSpice MediaWiki* was used in order to manage the relevant datasets. This open source software based on *MediaWiki* is especially developed for businesses solutions as an enterprise wiki (https://bluespice.com/ [July 23, 2019]).

4.2 Implementation

The AR maintenance application was implemented using the *Android Studio* environment and the *ArToolkit* package. Figure 4 shows the Unified Modelling Language (UML) diagram of the implementation. Here all the relevant augmented reality procedures (marker detection and overlay creation) were implemented using classes provided by *ArToolkit*. The maintenance instructions were generated using a dataset stored on the *MediaWiki* server. The data could be simply accessed using

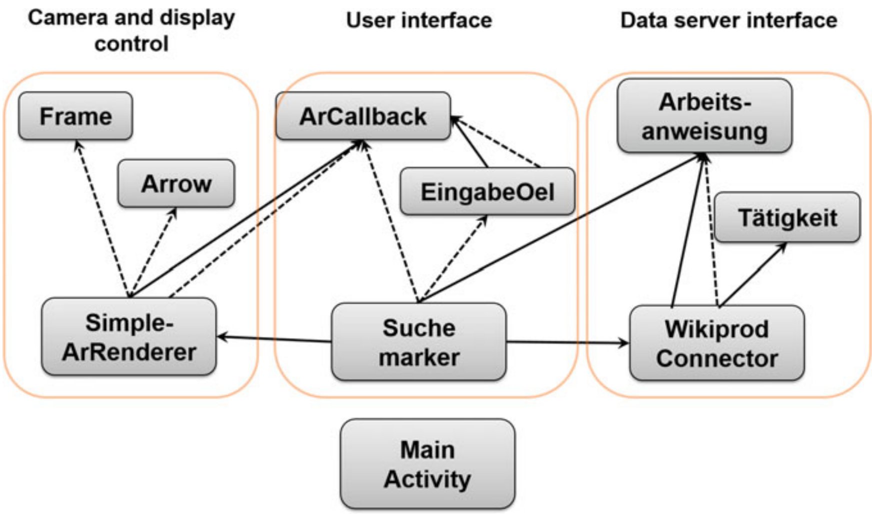

Fig. 4 UML diagram of the AR maintenance application implementation

the *MediaWiki* application programming interface (https://www.mediawiki.org/wiki/API:Main_page [July 23, 2019]). The data contained maintenance instructions as well as the information about the markers which should be detected by the device. In this prototype only a standard application layout provided by the *Android Studio* environment was used. In the case of the handheld device, a live camera view with additional was used. Smart glasses were used only the overlays were projected in the display using position information obtained from the markers.

4.3 Demonstration

The developed application was tested in several different environments in order to anticipate its applicability to environment with objects of different size and for different lightning conditions. Here for the test objects were labelled with several markers, which allowed the identification of the relevant steps and the maintenance parts. Figure 5 shows screenshots of the application test that have been run to evaluate the application stability in different environments. Here the typical camera view together with markers and overlays are shown. During the detection test, the *ArToolkit* based application was always able to detect the markers. Here typical working view angles and the typical laboratory lightning conditions were tested. Figure 6 shows the demonstration of the maintenance application on a typical maintenance machine as used in small manufacturing businesses. Here as well good performance of the marker detection could be stated for the chosen machine example. During the demonstration

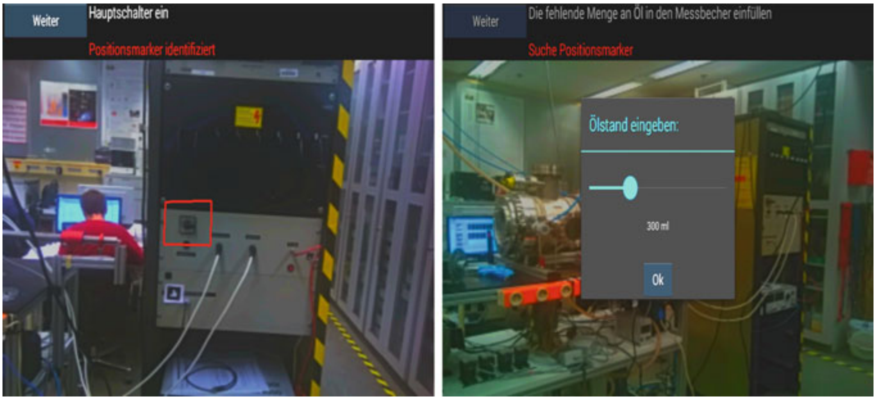

Fig. 5 Examples of the maintenance steps implementation as seen on the handheld device (Galaxy S3 smartphone) in a laboratory test environment

Fig. 6 Demonstration of the maintenance application on a typical manufacturing machine using smart glasses

a person, who never worked with this machine, was able to successfully perform all the maintenance steps without any further assistance.

The main issues raised by the test persons were the diminishing wearing comfort smart glass during the maintenance procedure and the rendering instabilities of the overlay, which is a known issue of *ARToolkit* mentioned earlier.

5 Summary and Conclusions

In this work an AR application for a typical maintenance process in a small manufacturing company was implemented. It was demonstrated, that by using open source SDK and software resources small effort needs to be taken in order to build an AR application. The latter achieves an acceptable performance in terms of providing information in augmented reality context. The application is only based on components provided by the SDK and the integrated development environment in order to minimise the development effort and costs. Although the demonstration of maintenance could be successfully performed on a test manufacturing machine, the test revealed that the wearing comfort is an important issue for the acceptance of the AR assisted maintenance by the workers.

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Customer Integration Through Virtual Reality Implementation: A SWOT Analysis in the Area of Production Systems

Elisa Landmann, Jana Stolz-Römmermann and Tobias Günther

Abstract During the last few years, the use of virtual reality (VR) technologies has become firmly established in large enterprises. In this article, the authors question the potential of implementing VR technologies to improve business to business (B2B) customer integration in the area of production systems. Many companies focus on increasing their customer orientation, and VR applications can provide greater integration into the service creation process. For clarification of the topic, a use case from plant engineering and mechanical engineering is presented. Technical opportunities and the risks of VR implementation for successful customer integration in the given use case are discussed. In addition, the resulting strengths and weaknesses for customer relationship management are shown. The article concludes with an outlook on future research needs.

Keywords Virtual reality · Production systems · Customer integration · SWOT analysis

1 Introduction

Strong competitive intensities mean that it can be reasonable in various areas to make targeted use of the knowledge of the customer or user. Therefore, the customer should not be underestimated as a valuable resource for the company (Franke, von Hippel, & Schreier, 2006). Consequently, it may be advisable to include the customer as an external factor in the service delivery process. Depending on the context, difficulties in communication can occur, because detailed agreements have to be made, especially for machine manufacturing processes; it may not be possible to do

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this to the required extent because of inadequacies in visualization. At this point, VR technologies can be used to superimpose the customer's senses and to enable a more detailed visualization. With the growing interpretation of VR applications, it is therefore possible to think about linking this with customer integration to generate competitive advantages through the efficient use of the customer's knowledge.

2 Issues

2.1 Customer Integration

Customer integration, also known as customer participation (Kelley, Donnelly, & Skinner, 1990), is considered to be a central feature of services, since customers' active participation is often essential in this context (Gouthier & Schmid, 2003). More recently customer integration as a management strategy has become increasingly well established in many kinds of industry. On the one hand, there is the possibility of transferring parts of the performance process to the customer, resulting in cost savings for the company and can be transformed into price advantages for the buyer (e.g. self-transported and self-assembled IKEA furniture). On the other hand, customer integration allows the customer's own ideas and knowledge to be brought into the creative process, and competitive advantages to be created (co-creation: Füller, Mühlbacher, Matzler, & Jawecki, 2009; co-designing: Berger & Piller, 2003).

In addition, purchasers are transmitters of valuable information about needs and solutions (Lilien, Morrison, Searls, Sonnack, & von Hippel, 2002). Moreover, customer integration can increase customer loyalty towards the company and its performance, since the products are user-specific and the creative process itself contributes to a personal emotional relationship (Piller, Moeslein, & Stotko, 2004). By way of limitation, it should be noted that any type of customer integration is limited by the ability and willingness of the customer and by risks, such as a strong dependency on the customer (Ballendat, Hütten, Antons, Niemand, & Siems, 2015; Moutongho Nzengue, N'Goala, & Kreziak, 2012). Furthermore, it is possible that a customer's misconduct may lead to unsuccessful customer integration (Greer, 2015).

2.2 Virtual Reality

There has been tremendous progress in the development of virtual reality technologies in recent decades. Virtual Reality (VR) focuses on human perception. The technology is based on the human information processing system, which is used and imitated to create a virtual experience. The perception of the user is manipulated in such a way that the offered stimuli can barely be distinguished from stimuli from the real environment (Jerald, 2016). Craig, Sherman, and Will (2009) refer to VR as a kind of computer simulation that creates a picture of a world that we perceive "in the same way as the real world" (p. 1).

Through technological advances, high quality VR systems are now capable of giving the spectator the impression of actually being in a virtual place (Slater, 2009). The mind processes the perceptions into an immersive experience. The immersion of the user is a central and much-studied differentiator between VR and other media (Bowman & McMahan, 2007; Witmer & Singer, 1998). Sherman and Craig (2018) have explored three additional key elements involved in VR: the virtual world, sensory feedback, and interactivity. Furthermore, the presentation and manipulation of virtual objects is very flexible, and the areas of product presentation and prototyping can profit from this.

In the industrial context, VR is used primarily in the decision-making process during product design. This happens mostly in the early stages and the conceptual phases of a project (Berg & Vance, 2017; Craig et al., 2009). VR visualization offers advantages that can benefit small and medium enterprises (SMEs). The medium is based on the possibility that a person, as if in reality, can explore and analyse a virtual scene by walking and looking around it in a natural way (Nilsson, Serafin, Steinicke, & Nordahl, 2018). Space requirements, proportions, visibility and aesthetic qualities can all be perceived in a way that traditional display technologies do not allow. As a result, the transparency and deep understanding of the product design can be increased. In recent years, VR technologies have arrived in the consumer area and are no longer reserved exclusively for research instituation or large companies (Avila & Bailey, 2014).

3 Procedures

3.1 Use Case

The authors are part of an interdisciplinary research group consisting of six industrial and six scientific partners. Their research focuses on the evolution of an assistance system for information and data transfer in the development process of production systems. The graphical assistance is intended to optimize the development process, especially in SMEs. One component of the system is the VR demonstrator, where the engineer views the created machine design drafts in an immersive environment at an early design stage. From the perspective of an individual, he can thus take up different positions and poses in a human way in order to examine the visibility of his solutions realistically. Are relevant areas recognizable? Is the view blocked by an object? In contrast to a standard display, these questions can now be clarified with the user's own movements. This idea can be transferred to ergonomic considerations and interaction evaluations: which operating elements are easily accessible for the user? Furthermore, the engineer gets a better idea of the space available for a machine and the possible restrictions of the environmental conditions. Exemplary scenarios and appropriate surroundings such as factory environments are provided for this purpose.

Finally, aesthetic qualities such as material properties can be analysed and checked under different lighting conditions. A disadvantage of traditional presentation forms like computer-aided design (CAD) renderings is the counterintuitive sight of the design proposals. A life-size representation of the design drafts permits a new kind of evaluation. This also improves the communication between the different disciplines involved in machine development, e.g. between the engineer and the controller of the development. In particular, customer communication benefits from an immersive presentation with a natural-human range of motion. Customers can explore their desired machine before it is physically manufactured, and can better evaluate the suitability of the solution. The presentation of 3D content based on CAD technology is fundamental for meeting customer needs during the development of a production system (Bellgran & Säfsten, 2009). The usual representation that is displayed requires a high degree of spatial imagination, which can lead to an increased cognitive burden and to deficits being overlooked. To obtain better customer integration in the business to business (B2B) context, the research group aims for a user-centred design of the demonstrator, and multimodal feedback to achieve an optimal user experience. For a long time, the immersive presentation of 3D content has been very costly and space-consuming (Choi, Jung, & Noh, 2015). With the introduction of powerful, inexpensive and mobile consumer head-mounted displays, VR presentations and virtual prototyping have become a possibility for SMEs.

3.2 SWOT Analysis

The present topic will be examined in more detail below by means of a SWOT analysis. In general, this form of analysis serves to identify factors that influence a company's competitive position (Leigh, 2006; Rizzo & Kim, 2005). However, the use of SWOT analysis goes beyond the corporate or competitive context itself, allowing the observation of general changes caused by internal and external influences on a subject over time (Leigh, 2006). Thus, general decision-making processes or an alternative assessment can also be considered and evaluated using this form of analysis (Hay & Castilla, 2006; Helms & Nixon, 2010).

SWOT is an acronym representing strengths, weaknesses, opportunities and threats. The term 'strength' refers to internal competencies or resources that promote the specific achievement of goals (Leigh, 2006; Rizzo & Kim, 2005). In the context of this paper, strengths are internal potentials for companies resulting from the implementation of VR. They are therefore internal prerequisites for successful customer integration. Weaknesses, on the other hand, denote limitations that prevent progress, or a lack of the skills needed by the company to compete against the external competition (Houben, Lenie, & Vanhoof, 1999; Leigh, 2006). In the context of this paper, weaknesses include those internal capabilities that are associated with the

Strength	Weaknesses
• Prevention of errors • Mature technology for visualization • Definition of design specifications (Bordegoni et al., 2011) • Enhanced productivity of engineering learning & training applications (Abulrub et al., 2011) • Exact representation of product scale (Rizzi, 2011) • Promotion of interdisciplinary understanding • Collaboration & mutual understanding enabled (Berg & Vance, 2017) • Strong immersion & interactivity • Enhanced presence (Rizzo & Kim, 2005) • Presence promotes constructive conversations	• Increased workload & time effort • VR not suitable for customer integration applications (Merlo et al., 2013) • Extra costs (Vignais et al., 2015) • Expert knowledge needed (Bartl et al., 2012) • VR systems not always intuitive to use (Berg & Vance, 2017) • 'Not Invented Here' syndrome (Antons & Piller, 2015) • Motionsickness (Kennedy et al.,1994) • Loss of information leading to misunderstandings (Enkel et al., 2005) • High problem potential due to rapid technological developments (Preece et al., 2002)
Opportunities	**Threats**
• Enhanced product design & superior quality → increased customer satisfaction (Mujber et al., 2004) • Immediate feedback with real-time reactions (Sherman & Craig 2018) • Retroactive view perspectives (Rizzo & Kim, 2005) • Evaluation prior to machine appearance • No risk of health hazards (Guo et al., 2012) • Application of theoretical knowledge to real industrial problems → customer education • Open-mindedness of customers • Advancing technological developments (Rizzo & Kim, 2005)	• Dependence (Gassmann et al., 2010) • Limitation by willingness/abilities of the customer (Gassmann et al., 2010) • Unfamiliarity of wearing a headset (McKone et al., 2016) • Misunderstandings due to reduced data precision • Exaggerated expectations (Rizzo & Kim, 2005) • Customer integration does not always increase efficiency (Danese & Romano, 2013)

Fig. 1 SWOT matrix including the results

usage of VR techniques rather than traditional visualization methods. Opportunities are external circumstances that support the achievement of the company's goals (Hay & Castilla, 2006). They are understood in this context as the benefits that result from VR-based customer integration for an improved customer relationship. Threats include those external factors that can potentially inhibit the company's performance (Leigh, 2006). Threats are challenges that arise during VR-based customer integration. The above-mentioned aspects can, for example, be viewed and developed within an interdisciplinary team and finally summarized in a matrix, which can be seen in Fig. 1. However, the division into internal (strength and weaknesses) and external factors (threats and opportunities) can be taken into account at any time.

4 Results of SWOT Analysis

4.1 Strengths

Different strengths can be determined with reference to the use case. The results of these and the following analyses can be seen in Fig. 1. In general, early customer integration leads to a strong relationship with the company's employees (Enkel, Kausch, & Gassmann, 2005), which can prevent errors in the early stages of a project. By exchanging or sharing information it is generally possible for a company to react directly to the needs and comments of its customers (Flynn, Huo, & Zhao, 2010;

Kim, 2006; Lee, Kwon, & Severance, 2007; Sezen, 2008). VR technologies are now easy to use, and also simple, as well as stable in their application (Berg & Vance, 2017), which is why the customer can be offered mature technology for visualization. Thus, fundamentally, customer integration is enabled.

VR can be used to define design specifications (Bordegoni, Ferrise, & Lizaranzu, 2011) and to provide methods for participatory development (Bruno & Muzzupappa, 2010). Additionally, the productivity of engineering learning and training applications can be improved with VR (Abulrub, Attridge, & Williams, 2011). Advantages result from the exact representation of the product scale, the immersive perception of the spatial expansion of the machine (Dünser, Steinbügl, Kaufmann, & Glück, 2006; Rizzi, 2011), and the contextualization of the content by the high visual quality of the virtual environment through texturing and lighting (Heydarian et al., 2015). A full-size representation promotes interdisciplinary understanding and helps to involve the customer actively in communication processes. The immersive value that is achieved means that communication as equals can be realized between all participants (Berg & Vance, 2017). Thus, an important aspect of customer integration is promoted by the ability for customers and companies to give mutual feedback on the current output at first hand (Zailani & Rajagopal, 2005). All in all, the use of VR applications enables collaboration and mutual understanding between different departments and customers. In the given use case, it is problematic that people from particular disciplines cannot clearly articulate their problems and requirements or formulate their difficulties only for solutions that already exist. This refers to people from different disciplines within a company and to customers from different branches. VR promotes mutual understanding (Berg & Vance, 2017), which can lead to open communication and therefore to a better understanding of the main issues.

Compared to conventional methods, VR applications enable stronger immersion and interactivity. Thus, the presence within the virtual environment can also be enhanced (Rizzo & Kim, 2005). A successful presence gives the person a feeling of being physically located within the virtually created environment (Berg & Vance, 2017). This presence can be perceived differently by each person (Moeller, 2008). Thus the customer can move in a natural-looking environment and view and evaluate the machine in the VR context, and constructive conversations with the company can be built upon this. In the area of production systems, not only designers, but also engineers and others involved in machine development can therefore take the opportunity to visualize the machine realistically, notice mistakes early on and prepare VR presentations for customers.

4.2 Weaknesses

With the application of VR comes a slightly increased workload, for instance, through data processing (Vignais et al., 2015). Industry-relevant formats, such as are also required in the use case mentioned above, are sometimes unreadable by VR presentation software. In conclusion, significant effort has to be put into the preparation and conversion of the different file formats that are required (Jimeno & Puerta, 2007; Tang & Gu, 2010). This and other weaknesses are summarized in Fig. 1. The polygonal structure of the VR data reduces the accuracy of surface representations. In some cases, where high resolution results are required, VR is not suitable for customer integration applications (Merlo, Sánchez Belenguer, Vendrell Vidal, Fantini, & Aliperta, 2013). Furthermore, the introduction of VR gadgets requires the company to incur costs (Vignais et al., 2015), such as for the training of employees and the acquisition of the necessary software and hardware, since the inclusion of already existing products cannot be guaranteed (Müller et al., 2016). Systems for VR visualization, such as head-mounted displays or CAVE systems, differ in, among other things, their acquisition costs, complexity and thus also their usability by SMEs (Bartl, Füller, Mühlbacher, & Ernst, 2012). For example, CAVE systems have comparatively high acquisition costs and also a very high space requirement, which is why they are rather unsuitable for use in SMEs; such companies would therefore have to resort to other methods in the given use case. In addition to the sometimes high acquisition costs, expert knowledge may possibly be necessary and can also be an obstacle to the integration of VR applications (Bartl et al., 2012). In general, problems can arise when dealing with VR systems, as their use is not yet as intuitive as the use of conventional systems (Berg & Vance, 2017). Therefore, a longer time is initially required to carry out conversion processes within the company, on the one hand, and to convince some customers about the use of the new technologies and the abandonment of old habits, on the other (Berg & Vance, 2017).

A general negative attitude of employees towards new technological implementations can be associated with the 'Not Invented Here' syndrome (Antons & Piller, 2015; Katz & Allen, 1982; Kostova & Roth, 2002). Thus, the possibility arises of the company itself resisting the implementation of VR technologies or the customer integration.

Customers can also reject the use of VR applications, since, for example, users of VR systems may experience problems that they want to avoid. In addition to the complete rejection of the application, there can also be a premature termination of the use of VR media. This can weaken or even impair the customer integration, because the viewing of a virtual environment cannot be completely carried out and the complaints after such an experience can prevent the reuse of VR systems. Motion sickness can, in particular, become problematic, and in these circumstances disorientation or nausea can occur or the users may feel ill when moving their heads. In addition, further after-effects such as flashbacks can occur, and these are perceived as unpleasant (Kennedy & Stanney, 1996; Rolland, Biocca, Barlow, & Kancherla, 1995).

Furthermore, a loss of information can be expected when using VR systems. At first, this can occur between different departments, including in the given use case, as discrepancies can exist between departments due to different focuses in the VR representation. First, it has to be clarified whether the focus in the representation is on visual or functional issues (Berg & Vance, 2017). This also influences the level of detail at which the customer can view the VR representation. At this point of contact, too, further information losses or misunderstandings can occur (Enkel et al., 2005), depending on the representation form that was previously selected. Such losses can also cause a lower level of understanding on the part of the customer, which in turn reduces the likelihood of a successful communication process and slows down customer integration.

In general, the continuing rapid developments in the field of VR-related technology can be problematic. Conventional 2D interfaces have a lower potential for problems, as they have been established for a long time and are therefore more mature. If VR applications cannot be used without errors, this can lead to problems during customer contact, which may have a negative impact on customer integration or, in the case of a temporarily non-functional application, can even stop integration completely.

4.3 Opportunities

Effective implementation of VR technologies in manufacturing processes can result in enhanced product design, with superior quality, leading to increased customer satisfaction (Mujber, Szecsi, & Hashmi, 2004), an opportunity also mentioned in Fig. 1. In the early production stages, VR can be used to define the initial machine structures based on functional requirements (Zwolinski, Tichkiewitch, & Sghaier, 2007). This can be carried out by working together with the customer, as mutual understanding is improved by using VR applications in the use case. Since VR systems can provide immediate feedback based on real-time reactions (Sherman & Craig, 2018), this promotes interaction and communication between the customer and the company. After the customer's view has been transferred into VR, it is possible retroactively to view what he has seen from different perspectives (Rizzo & Kim, 2005). Thus, detailed agreements and case-by-case problem solving are possible, and these are fundamental in the use case. They allow the customer in this special case to bring its knowledge and concerns to the table in a precise manner, which increases the understanding of these issues on the part of engineers and other stakeholders within the company.

Virtual prototyping enables machines, including their functionality, ergonomics and ease of use, to be evaluated prior to their appearance on the market (Bao, Jin, Gu, Yan, & Ma, 2002; Berg & Vance, 2017). For instance, in plant engineering and mechanical engineering, reaching and viewing distances can be analysed interactively in real time by the engineer and the future user of the machine for the better ergonomic positioning and alignment of the machine elements. Furthermore, users can inspect machines or processes in virtual training scenarios without disrupting any real processes or incurring any health risks (Guo, Li, Chan, & Skitmore, 2012; Hoberman, Krum, Suma, & Bolas, 2012). Moreover, it is often easier for people to apply their theoretical knowledge to real industrial problems. This opens up the potential for customer education through VR applications, like specific training sessions for the future users of a machine.

The public ‘hype’ of VR technologies (Jerald, 2016) can generally be assumed to lead to open-mindedness and curiosity by customers. It is precisely these that the company needs to build on and exploit for successful customer integration. In the case of enthusiastic customers, the probability of rejecting VR technologies is very low. This open-mindedness can therefore also promote communication between customers and companies.

Sometimes the acquisition costs for VR applications are quite low. This is particularly assisted by the advancing technological developments of mobile phones and tablets (Anthes, García-Hernández, Wiedemann, & Kranzlmüller, 2016; Berg & Vance, 2017). These can also be actively used for VR displays. Thus, the prerequisites and monetary hurdles for the use of VR media are very low in some cases, so that customer integration can take place effectively through the use of VR applications.

4.4 Threats

In general, customer integration should take account of the fact that customers and especially the company become dependent on each other. This can also lead to a loss of knowledge within the company (Enkel et al., 2005). However, the prerequisites for customer integration are only available to a limited extent if there is no knowledge or information provided by the customer or the design, construction and all other processes for machine creation all lie within the company (Moeller, 2008).

Furthermore, it should be noted that any type of customer integration is limited by the ability and willingness of the customer, as well as other factors, such as a strong dependency of the company on the client (Gassmann, Kausch, & Enkel, 2010; Moutongho Nzengue et al., 2012). These threats are also summarized in Fig. 1. It should be taken into consideration that some VR interactions become problematic for people with cognitive or physical impairments if, for example, joysticks are used (Rizzo & Kim, 2005). Also in this case reactions from the customer against the use of VR media can occur. Moreover, the unfamiliarity of wearing a headset (McKone, Haslehurst, & Steingoltz, 2016) can lead to a rejection of the technology by the customer, who in the given use case would be the company selling the machine. Also, the possible reduction in precision in data representation can lead to problems of visualization and understanding in machine agreements with mechanical engineering companies. Inaccuracies in the presentation may cause misunderstandings depending on the imagination of the customer can appear.

Even if the possible ‘hype’ about VR applications can trigger curiosity in some people, as already mentioned, the users’ expectations can also be excessive and thus never be met (Rizzo & Kim, 2005). In the case of excessive or unrealistic expectations, there is the possibility that customers are disappointed after the presentation via VR, and do not see any advantage in the VR application compared to conventional methods; they may thus reject its use in the future. In this case, customer integration via VR would fail.

Furthermore, studies show that customer integration does not necessarily lead to improved efficiency (Danese & Romano, 2013). This can lead to customer integration not delivering the expected results, or to customer integration within the company being undesirable.

5 Conclusion

All in all, the use of VR technologies can influence communication on different levels. Thus an influence on the internal communication processes within or between teams, but also externally between customers and the employees of a company, is possible (Berg & Vance, 2017). VR can therefore lead to generally optimized communication processes, but it can also promote successful customer integration. Such integration can provide the company with valuable knowledge, for example, or can lead to cost savings through the possibility of early troubleshooting. Because of the simplified collaboration by means of the employment of an innovative technology in the form of VR, valuable competitive advantage can be generated (Lusch, Vargo, & O'Brien, 2007). Finally, the ultimate use of the machine by the customer can be promoted (Urban & Hauser, 2004; Verona, Prandelli, & Sawhney, 2006), which strengthens the customer relationship and supports the positive prerequisites for future projects with renewed customer integration. Nevertheless, the use of VR for customer integration sometimes leads to some unavoidable weaknesses and threats, such as perceived motion sickness and negative reactions towards the application of VR media. In this case, it is not possible to achieve successful customer integration. Furthermore, with this approach it should be borne in mind that customer integration via VR applications is only one possible solution, is only suitable for companies on a case-by-case basis, and is subject to limitations such as a loss of information in communication or strong dependencies on the customer. The results indicate that the benefits that have been considered outweigh the risks identified here. Therefore, the implementation of VR technology can be recommended.

All mentioned results are summarized in Fig. 1 to give a further overview of the analysis findings.

This research indicates that the implementation of VR technology in customer integration shows promising effects in the B2B context that is presented. The examination of this assumption shows a research gap. In particular, the effects of the implementation of VR technology on customer experience, customer satisfaction and communication should be tested empirically in the B2B field. In addition, further research should investigate the potential offered by the use of VR technology for customer education and the early avoidance of errors. However, outside the VR context, studies (Danese & Romano, 2013) show that, in general, customer integration does not necessarily lead to increased efficiency. Further studies can re-examine this research context by linking the question to VR media. Moreover, SWOT analysis monitors changes, which consequently means that such an analysis should be carried out again with a slight time lag, not least because of the rapid technological developments. In this way, changes or shifts within the SWOT matrix can be detected and visualized.

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AR and VR in Education

Digital Literacies in Virtual Reality Learning Contexts

Volker Eisenlauer

Abstract Recent virtual reality (VR) applications are on the cutting edge of learning technologies designed to trigger self-directed and holistic learning experiences. However, learning via and within VR does not start from scratch; it depends on our understanding of preceding learning technologies. This paper explores key tenets in the concept of digital literacies and discusses their applicability to VR-enhanced learning environments. More specifically, it focuses on meaning-making practices in 360-degree media that incorporate and expand upon skills and competencies associated with hypertextual reading and writing. Based on two prototype cases designed and implemented by students with no technical background knowledge, the paper identifies generic steps for the creation of 360-degree media learning environments. The student projects serve as a showcase for how VR development is moving beyond the specialized and exclusive domain of software engineers and becoming an increasingly textual practice that integrates and enhances skills and competencies associated with preceding writing technologies.

Keywords Hypertextual literacies · VR literacies · 360-degree media · VR enhanced learning · Media education

1 Introduction

Recent VR applications are on the cutting edge of learning technologies designed to facilitate self-directed and holistic learning experiences. The visually engaging and immersive learning environments provide contextualized input by simultaneously reducing and extending human action and experience. Although there is scientific consensus that VR technologies can be effective in acquiring new skills and knowledge (Domingo & Bradley, 2018), the underlying literacies that link VR and learning remain widely unexplored. Existing studies commonly focus on basic operational skills in VR technologies or examine at a more general level the acceptance of VR learning environments (Huang, Liaw, & Lai, 2016). Long before VR technologies

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hit the consumer market, Sherman and Craig (1995) compared the appropriation of VR media to acquiring a new language that is made up of new signs and has its own syntax. Although VR as a new medium has not yet fully reinforced its symbolic codes and conventions, the afforded semiotic practices do not appear from nowhere, but stand in a long tradition of preceding media technologies and its corresponding literacies. This paper examines meaning-making practices in VR learning contexts by disclosing the ways VR literacies incorporate and enhance skills and competencies required for earlier digital media use. Section 2 introduces the concept of digital literacy and investigates how hypertextual practices give access to understanding innovative VR systems. Sections 3 and 4 provide a concise outline of the key concepts of study, i.e. virtual reality, 360-degree media and VR enhanced learning. Section 5 shifts the focus onto how university students employ VR technologies and identifies generic steps for the creation of 360-degree VR learning environments. Section 6 discusses and summarizes the most important results and identifies two literacy practices specific to meaning making via and within VR.

2 Digital Literacies in VR Systems

The literacy skills required by digital media have been referred to differently in academia and beyond. Educational researchers and practitioners suggest the concept of multiliteracies to draw attention to both an increase in multimodal textual practices and in cultural and linguistic diversity, which go hand in hand with social and technological changes (cf. Pillay, 2010). (Inter-)national organisations and policy makers consider the concept of information literacy "crucially important to enable people to deal with the challenge of making good use of information and communication technology" (Horton, 2008, p. I). The concept of digital literacies is widespread in both education studies (Pietraß, 2010) and communication (Jones & Hafner, 2012). Using the model of literacy as a social practice (Street, 1984) as a starting point, approaches to digital literacy study various communicative practices in digital media, e.g. hypertextual reading/writing (Bublitz, 2005), multimodal meaning creation (Lim, 2018) and video games as literacy (Gee, 2007). Researchers describe competencies for a critical and fruitful engagement with digital media in terms of lists of behavioural and social skills. They include novel text processing skills, such as understanding non-sequential material, assembling and evaluating texts from different sources or filtering incoming information (Bawden, 2008). Other researchers have been investigating innovations in text productions, such as remix and sampling (Hafner, 2015) and text automation (Eisenlauer, 2017), and highlight new ways of participating via and within digital media (Jenkins, Itō, & Boyd, 2016).

Insights from media linguistics (Eisenlauer, 2013) have identified criteria that delineate digital hypertexts from traditional non-digital texts: In contrast to traditional print texts, digital hypertexts escape clear demarcations and fixed structures. Interactive users assemble individual text fragments to cohesive and coherent wholes when clicking hyperlinks or performing other operations, such as liking, sharing, commenting or conducting online searches. The high fragmentation and digital linking of hypertexts afford multiple ways of reading and writing. Accordingly, the structure and contents of digital hypertext arise as a function of the users' hypertextual literacy practices, which can be described based on four specific criteria: *multilinearity*, *fragmentation*, *multimodality* and i*nteraction*; see Table 1.

What is evident at first glance when comparing VR and hypertext systems for their underlying literacies is that in VR, images are used as the dominant mode. As opposed to this, in hypertexts the main idea is commonly conveyed verbally, while images are of secondary importance. Structural similarities can be found in the ways users access and interact with hypertexts and VR systems: Just like websites that offer multiple reading parts to choose from, VR users are free in terms of where to look or to go or what to do next. Hypertextual literacy practices specify not only complex meaning-making practices in current media environments, such as websites, social network sites or blogs, but also shape our understanding of emergent media technologies, such as VR. Before elaborating on how the four criteria of hypertextual literacy practices offer a key to understanding both formal and functional features of VR learning environments, it is necessary to clarify the concepts of VR and 360-degree media.

Table 1 Criteria of hypertextual literacy practices

Multilinearity	Digital hypertexts can be combined in multilinear ways offering multiple reading paths and meaning-making potentials. Users select from a variety of content offers and are constantly pondering what to read, where to go and/or what to do next
Fragmentation	Fragmentation concerns "the granulated text pieces which are inter-connectable into meaningful wholes. It can be distinguished between intranodal and internodal fragmentation, referring to the fragmentary text arrangement within one and the same node or across different nodes. Further we can distinguish between intramodal and intermodal fragmentation concerning a textual segmentation within or across different semiotic modes" (Eisenlauer & Hofmann, 2010, p. 88)
Interaction	Interaction relates to the interactive role of users when engaging in meaning making via and within digital media and can be investigated along three levels. On a formal-structural level, users engage in the composition and actualization of text material, which is then interpreted and understood on a cognitive level. On a productive level, users may participate in the creation of text content, when for example commenting, sharing or extending other-authored information
Multimodality	Multimodality concerns new facilities for composing, integrating and displaying a wide range of different representational formats, such as text, photo, audio and video. Although not a unique feature of hypertexts, digital tools are technologically more convenient for composing multimodal texts and offer various functions for remixing and combining other-authored content into a communicative artefact

3 Virtual Reality and 360-Degree Media

Head-mounted displays, such as the Oculus Rift, HTC Vive or Samsung Gear, are among the most iconic objects associated with the concept of VR. In an everyday understanding, everything that can be viewed through head-mounted displays, colloquially also referred to as VR glasses, is VR. However, as Sherman and Craig (2019) showed, head-mounted displays are neither necessary nor sufficient for experiencing VR worlds. According to the authors, there are four key elements that build the foundation for the creation of VR experiences: a *virtual world*, *immersion*, *sensory feedback* and *interactivity*.

The concept of a *virtual world* refers to the mediated content and embraces the formation of imaginary spaces and shared knowledge between producers and recipients. A virtual world can exist solely in the mind and independently of VR interfaces as a purely imaginary construct. When shared with others, imagined virtual spaces are transformed into semiotic form, such as speech, a novel, a music notation or a stage play, which can be brought to life by artists. In computer-based virtual worlds, the envisioned spaces and objects are simulated in software models, which can be experienced in a physically immersive and interactive way via VR systems.

The second key element is called *immersion* and refers to perceiving an alternate reality, i.e. a space that is different from the user's non-mediated physical surrounding. Such a feeling of presence in an alternative space can be reached on a purely mental level, for example when reading a book or watching a movie. In addition to mental immersion, VR allows for physical presence. The impression of entering the virtual world is to a great extent based on physical immersion, which is directed at users' senses and enables embodied experiences.

Sensory feedback adds to the immersive experience by tracking users' movements and providing new stimuli in reaction to their actions in real-time. Most commonly, VR-afforded sensory feedback appeals to the visual sense, although some VR services enable haptic touch and olfactory experiences (see Serrano, Baños, & Botella, 2016).

Interactivity refers to user engagement with the presented virtual worlds and involves a medial and a social dimension: As virtual worlds unfold, users manipulate simulated objects and thus engage in the creation of the alternate space, for example by making use of preselected options in printed interactive gamebooks or by moving position or laser pointing in VR systems. Moreover, collaborative virtual environments allow for collaboration among various users via and within the same virtual space. Considering these key elements, Sherman and Craig (2019, p. 16) defined VR as follows:

> A medium composed of interactive computer simulations that sense the participant's position and actions and replace or augment the feedback to one or more senses, giving the feeling of being mentally immersed or present in the simulation (a virtual world).

The concept of 360-degree media is often used interchangeably with VR systems. From a mere technical perspective, 360-degree media refer to spherical or panoramic images created with omnidirectional cameras while VR systems can be defined as

Table 2 Distinguishing VR systems from 360-degree media

	VR systems	360-degree media
Materiality	• Constructed animations • Based on computer graphics and real-time rendering	• Captured physical world events • Based on photo, film and audio
Interactivity	• Full-body experiences cf. walking around, grabbing things • Collaboration with others via and within VR	• Visual and aural experiences, listening and looking around • Interactive experiences via hotspots
Agency	• Using the whole body to transform intentions into actions	• Deciding where to look next

"integrated collection[s] of hardware, software, and content assembled for producing virtual reality experiences" (Sherman & Craig, 2019, p. 7). Although both 360-degree media and VR systems can be accessed with head-mounted displays and afford mental and physical immersions, they differ in the *materiality of the employed signs*, in the *interactivity of the delivered conte*nt as well as in *varying degrees of agency* perceived by the users, see Table 2.

The presented worlds in VR systems are most commonly composed of computer-generated image data, i.e. computer graphics, such as pictures and films that were created with help of dedicated software applications. In contrast, 360-degree media are based on the (audio-)visual recording of events, actions or places in the physical world. They enable the presentation of multiple viewing angles simultaneously and suggest spatiality. The depicted three-dimensionality calls for active recipients that engage in exploring multiple views of the depicted scenes and spaces by simply turning their heads. In some 360-degree media, users may access additional contents via hotspots, i.e. linked markers that activate additional 2D media content, such as texts, photos or audio recordings, or create transitions between different 360-degree sequences. Content for VR systems is often created with the help of game engines, such as Unity or Unreal. Such software development tools are designed for building video games and typically support the creation, animation and display of 3D spaces and objects. Due to their ontological quality, computer-generated assets can be rendered in real time and in response to various user stimuli. Real-time rendering together with the advanced tracking of movements provides users with full-body experiences and enables meeting and collaborating with others via and within the VR environments. Users can thus perceive an enhanced sense of agency in which they can direct their own explorations, cf. by walking around, and may perform a great variety of goal-oriented actions, such as picking up a virtual wrench, throwing a ball or meeting with other users.

4 VR-Enhanced Learning

The experiential nature of 360-degree media is in line with constructivist approaches to learning. Based on constructivist theory (cf. Piaget, 1950/1975), learners actively (co-)construct new knowledge and skills through personal experience. "Knowledge is not merely a commodity to be transmitted, encoded, retained, and re-applied, but a personal experience to be constructed" (Ackermann, 2005, p. 7). Accordingly, teaching materials can increase learner success most efficiently when enabling learners to build their own knowledge systems in their own learning environments. Constructivist-informed teaching models (Kamii & Joseph, 1989) therefore focus on creating authentic contexts of practice, i.e. real-life activities that naturally occur in the learners' environments but must be designed and implemented by the instructor to happen in the classroom or learning space. According to Swan (2005), the most significant implication of constructivism for teaching is "to shift the focus of pedagogical design away from instruction and toward the design of learning environments" (Swan, 2005, p. 26). Learning environments are understood as (virtual) spaces that trigger and support active learning.

Following Bransford (2002) as well as Swan (2005), the design and implementation of learning environments can be approached from four interconnected perspectives, i.e. learner-, knowledge-, assessment- and community-centred.

- The learner-centred perspective places the learner and her/his individual values, expectations, motivation and prior knowledge at the heart of learning. Learner-centred environments build on concepts and knowledge students bring with them when entering the learning space. Therefore, developers need to get a sense of what students know already and what their attitudes and beliefs towards the learning experiences are.
- The knowledge-centred perspective recognizes learners' need to develop learning strategies that lead to understanding and knowledge transfer. Such learning strategies can be supported through learning activities in authentic contexts of practice, wherein students engage in authentic problem solving and critical thinking tasks.
- The assessment-centred design of learning environments focuses on assessment and feedback instruments that guide, motivate and correct learners. The emphasis is laid on the individual processing of environmental feedback among learners. On the basis of effective self-assessment practices, learners continuously reconstruct their knowledge to achieve a more complete understanding of the subject matter.
- The community-centred perspective recognizes the importance of situating learning activities in particular communities of practice, such as the community of the classroom or the school, as well as in connected domains of life, such as the home and friends/peers outside of schools.

The affordances of VR and 360-degree media provide new opportunities for integrating these perspectives into practice. Immersive learning environments not only offer the possibility to recreate different aspects of reality, but also allow for customization according to individual learners' backgrounds and preferences. Through interacting with and manipulating VR and 360-degree content, learners construct meaningful experiences that will in turn represent new knowledge in interpretable and understandable forms. Moreover, immersive learning environments allow learners to do and experience things that would be impossible in real life, such as practicing public speaking without consequences (see Virtual Speech) or travelling through the blood stream (see The Body VR). As Hu-Au and Lee (2017) have shown, teachers may take their students on virtual fields trips via VR and 360-degree media. "This creates powerful learning opportunities for experiencing historical contexts, scientific environments, and personally meaningful moments" (2017, p. 220). Some learning apps, such as Google expeditions, provide not only authentic contexts of practice but empower students to create their own learning spaces.

In addition, VR systems and 360-degree media provide new opportunities for giving learner feedback in effective and intuitive ways. Eaves, Breslin, and van Schaik (2011) highlighted how the learning of complex dance movements benefits from real-time VR feedback. Intelligent tutoring systems in immersive learning spaces provide real-time advice to learners to ensure that they reach appropriate learning goals. VR systems and 360-degree media foster interaction and collaboration among learners. Sophisticated VR environments, such Facebook Spaces VR, are increasingly designed for users to collaborate with other users and/or with simulated peers. As opposed to pre-specified learning spaces provided by software developers, collaborative VR learning projects realized by students (see Cochrane, 2016) foster community building and knowledge sharing.

While immersive learning spaces provide new opportunities for constructivist learning experiences, the use of VR and 360-degree media does not automatically lead to improved learning. In fact, the novelty of experiencing immersive learning spaces may even distract learners from presented content (Rupp et al., 2016). It is therefore important to design learning environments in a way that gives room for becoming acquainted with the novel tools, i.e. by presenting material with a low intrinsic cognitive load (Sweller, Ayres, & Kalyuga, 2011).

5 A Case Study on Student-Created Learning Spaces

The remainder of this paper shifts the focus onto how students created their own VR learning spaces in two different academic contexts. The sample comprises two media education students from the Bundeswehr University Munich and five teacher trainees from the University of Klagenfurt, all aged between 18 and 23. The media education students had previous experience with VR within the last six months; one stated he owned a private VR device. None of the teacher trainees had previously used VR systems. To reduce barriers for content generation and allow for non-coding savvy students to create learning spaces, the use of a 360-degree camera was preferred over the use of computer-generated images for content production.

Table 3 Generic steps for the creation of immersive learning spaces

Drafting the learning space	Shooting the 360-degree sequences	Editing and delivering the learning experience
Specifying of subject matter and teaching aims Review of textbooks and digital teaching resources with similar teaching aims Description of film, photo and audio material to be produced	Deciding on the location, roles and props Positioning the camera operator and the camera and the audio recorder Directing the actors and positioning the props	Editing the recorded photo/film and audio material Staging the material via a publishing platform/game engine Implementing hot spots and transmissions to the next sequence

Table 3 illustrates the 360-degree VR video workflow, from drafting the learning space to delivering the learning experience. The workflow is based on previous research into 360-degree video production (Feurstein, 2018; Wohl, 2019) that identifies generic steps and hands-on practices for creating 360-degree videos. The described production stages were extended and adjusted according to the objectives of the student project, i.e. the design and implementation of 360-degree VR learning environments.

The media education students implemented a VR learning space aimed at presenting crucial information on the student facilities and services on campus. The VR campus tour helps prospective and international students gain a first impression of the university. Before drafting the tour manuscript, the students reviewed virtual 2D campus tours as presented on various German university websites as well as Google's 360-degree tour creator. This helped them to determine what to present and how the contents may benefit from VR. During the shooting of 360-degree films, the camera was positioned in a way that resembled the eye level and position of a participant attending the campus tour. The student tour guide moved around and pointed at various points of interests within the environment aiming at VR viewers following his movements. As part of the editing phase, the students reviewed and revised the footage and created four one-minute sequences that portray different sights on campus. The finalized films were then delivered to a head-mounted display with the help of the game engine Unity. Although none of the students had a background in coding, they managed to adapt the Interactive 360 Sample Project template offered in the Unity asset store for their own purposes. Figure 1 illustrates a screenshot of the VR experience. The viewer can traverse between the individual sights by gazing at the white squares for three seconds.

The 360 VR learning space created by the teacher trainees aims at teaching English as a second language. The students displayed a deep understanding of the English language and received training in language didactics and teaching methods. After a basic introduction into 360-degree media and VR systems, the teacher trainees reviewed textbooks designed for the English classroom. The aim of the review was to identify exercises and tasks that would benefit from a VR learning experience. As opposed to the media education students, the teacher trainees refrained from using 360-degree films and instead realized their projects with the help of audio recordings

Fig. 1 VR campus tour

and 360-degree photos. After reviewing and selecting the appropriate photos and recordings, the material was staged with help of the 360-degree publishing and image editing platform ThingLink. The platform not only supports the viewing of fully spherical panoramic pictures but offers various possibility to create interactive experiences via hotspots that activate additional content, such as audio files or images.

Figure 2 shows a screenshot of one of the student-created VR learning environments. The learning aim here is the acquisition of English prepositions. The viewer can activate individual recordings of how to use prepositions by gazing at question marks next to individual objects placed in the portrayed spherical scenery, here "the

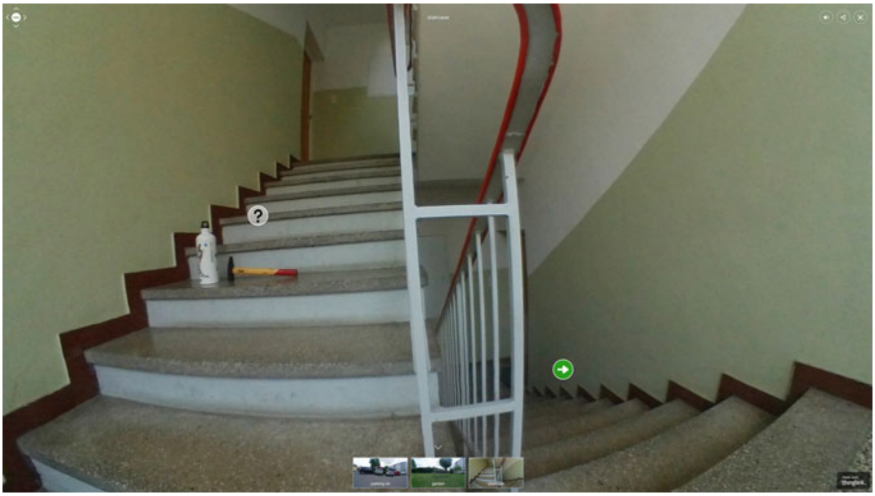

Fig. 2 VR English learning

hammer is next to the bottle". After completing the 360 VR learning experience, the learner is required to apply the introduced prepositions as part of a multiple-choice test.

In each class, the students presented their final projects on the last day of the course. Following this, each student was given a survey asking them to identify and reflect on the major challenges they faced during the different phases of the production workflow. A second set of questions aimed at determining the role of hypertextual literacies for creating and understanding 360 VR experiences. In particular, the questions were designed to elicit information on perceived similarities between literacy practices in hypertexts and in VR systems.

6 Discussion and Conclusion

The analysis gives insights into the two sample groups' VR literacy practices when designing and implementing immersive learning spaces with the help of 360-degree media. Special emphasis is placed on the required skills and competencies associated with VR content production.

The most common problem the teacher trainees encountered when drafting the learning experience was to envision the panoramic learning space and to mentally move around and explore the imagined space from different angles. As opposed to the teacher trainees, none of the media educations students addressed the challenge of envisioning the learning spaces. As the two groups' previous VR experiences differ significantly, it can be argued that such differences result in varying skills of envisioning VR worlds. The two groups displayed a common problem when shooting the sequences: positioning the camera and the camera operator. As a general rule, in 360-degree media the distinction between being in front of and behind the camera has dissolved (Tricart, 2018). Therefore, operating the camera became a challenge. The sample participants operated the cameras remotely using their smartphones but had to find spots where they would not be captured on camera. Moreover, when positioning the cameras, the students had to take the viewer into consideration, who would experience a sense of presence via and within the recorded footage. One of the teacher trainees reported that the best camera position was found based on an imagined participant involved in the action portrayed. As part of the editing and delivery phase, the sample groups faced a variety of technical challenges, such as importing the footage, organising the scenes and takes, viewing the material and assembling a final cut. Although the media education students who had training in film production outperformed the teacher trainees, the latter created high-quality sequences in skilful and creative ways. In relation to staging the material, the sample groups decided on different publishing platforms and had to overcome varying degrees of technical challenges. The teacher trainees operated the publishing platform ThingLink intuitively and staged, organised and linked their material with great ease. The media education students who created their VR campus tour with the help of Unity faced difficulties when integrating and linking their footage. They reported to have overcome challenges and problems they have encountered with the help of YouTube tutorials. Members of both groups described the challenge of arranging the material in a way that would provide some sort of guidance to the users. One of the teacher trainees expressed her concern that users would not discover the hotspots if they were not included in the frontal view of the scenery.

In relation to perceived similarities between hypertext and VR literacies, the teacher trainees identified VR hotspots as immersive counterparts to hyperlinks in websites. Moreover, members of this group addressed the common pattern of interacting with the content and having the freedom to decide what to read and/or where to go next. The media education students addressed similarities between VR learning spaces and a particular digital genre, i.e. video games. Both are built in three dimensions. Just like VR users, video game players have agency, that is they may perform a variety of actions within the gaming space.

The findings of this study revealed an array of productive and receptive competencies required for semiotic practices via and within VR learning contexts. Since VR meaning-making practices establish a somewhat understudied field, the study explored not only new ways of using VR in academic contexts, but also specified fundamental theoretical concepts. In the latter sense, VR systems can be distinguished from 360-degree media based on differences in the materiality of the employed signs, in the interactivity of the delivered content as well as in varying degrees of agency perceived by the users.

360-degree media reduce barriers to create VR experiences that support a constructivist approach to learning. Transcending the mere ability to create and deliver 360-degree content, *VR literacies* can be distinguished in terms of two meaning-making practices: *envisioning immersive spaces* when drafting and shooting the VR sceneries and *anticipating user agency* when editing and staging the material. These competencies incorporate and extend the multilinear, interactive and multimodal practices identified for understanding preceding hypertextual media. The four criteria of hypertextual literacies therefore offer a key to understanding both formal and functional features of VR systems: VR users are no longer recipients or observers, but instead involved participants who decide when to look where. More specifically, VR users are free to move and rotate their heads/bodies along vertical and horizontal directions while looking around exploring whatever captures their attention. As a result, VR participants "mentally piece together elements of the story and create meaning of their own. No two participants will see the same things in the same order" (Tricart, 2018, p. 99). Likewise, VR systems stand out through fragmentation in the form of self-secluded content clusters: individual scenes, sequences or episodes are received as cohesive and coherent wholes that can be combined in individual multilinear ways. VR participants may interact with and traverse the presented content clusters in individual ways to combine them into meaningful experiences and stories. Such a reassembly is built on the participants' interaction with the VR system that encompasses not only physically experiencing the proposed worlds, but moreover its cognitive processing as well as possibilities for expanding the pre-set content clusters. The perception of physically interacting with virtual worlds together with the cognitive processing thereof is at the very heart of what creates the feeling of presence in VR.

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Towards a Taxonomy of Virtual Reality Usage in Education: A Systematic Review

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Abstract Virtual reality market is undergoing a rapid extension and continually evolves with technological advancements. Today it is populated with solutions which are complex in terms of interaction and graphics. One such example is applications for educational purposes, a distinct class of VR solutions, development of which implies consideration of multiple disciplines. However, there is still no standard general-purposes classification of those solutions. Different interested parties develop separate and mosaic categorizations based on their field, audience and purposes. This paper reviews reported classification schemes of using virtual reality for learning and summarizes them towards a taxonomy. It tries to implement a multidisciplinary approach, without focusing on one particular aspect, but rather integrating prospects from such fields as human-computer interaction, pedagogy, psychology, and technology. The paper provides a brief overview of existing veins of VR research on education and training as well as proposes relevant research directions.

Keywords Systematic review · Virtual reality · Learning · Educational technology · Classification

1 Introduction

Virtual reality (VR) technologies are being used today in plenty of contexts: entertainment, research, education. Considering the declining cost, it becomes the convenient medium for learning when the real experience is dangerous, or merely conjugated with the difficulties of the implementation, like an illustrative stroll on the surface of Mars. From the begin of the research on VR more than a half a century ago, it has been encompassing questions of making the experience more seamless and immersive, developing new ways of interaction, and dealing with perceptual factors. In the scope of education, researchers primarily have been trying to identify critical factors making learning with digital realities more preferable than conventional instructional tools, especially in terms of learning outcomes. Among other

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benefits of its use in educational purposes, it has been reported about its high interactivity and attractiveness for users, making it possible to reflect on the educational experience in emotional form. Previously there were doubts on its usefulness (e.g. linked to usability issues), but persistent development of the technologies withdraws the objection. VR educational solutions saturate the market in various forms and genres, disciplines and purposes, but there is still no overarching general-purposes classification of them. Existing classifications dissect them from the different sole perspectives, depending on which field the authors are from, and provide a mosaic view on the complex phenomenon. This paper is an attempt to review existing classification schemes of educational VR uses and to summarize them in a taxonomy. The paper begins with a short overview of the VR background knowledge and previous works in the field, following a systematic review of classifications, resulted in a general taxonomy. The present taxonomy could help to shed light on the issues in current research and integrate multiple perspectives on the phenomenon as well as could serve as a framework for development and evaluation of educational VR applications.

2 Literature Review

2.1 Concept of Virtual Reality

Although exact VR definitions are not entirely unanimous and often descriptive, essentially they all come down to a technologically generated representation of a 3D environment (Kavanagh, Luxton-Reilly, Wuensche, & Plimmer, 2017). Sherman and Craig (2003) defined four pivotal components of VR: a virtual world, immersion, sensory feedback, and interactivity. A *virtual world* (VW) is the content of a medium (VR): all the objects populating an imaginary space with rules between them. One can experience a VW without interacting with an immediate VR system (software, hardware, and content integrated to create VR experience; Sherman & Craig, 2003). *Immersion* is the sense of being present and involved in the experience rather than just observing a VW from the outside. *Sensory feedback* is critical to the immersion provision of sensational information (visual, haptic, etc.) about the virtual environment based on user input. *Interactivity* is the characteristic of a VW to be responsive to user input; an ability to affect the VW and be affected by it in exchange. The degree of the implementation of these four components can illustrate both broad and narrow definitions of VR. The letter would only include fully immersive and interactive instances, as, e.g. those experienced with head-mounted displays; whereas the former would include such forms of VR as screen-based VWs.

Virtual environment is another term often being used as a synonym for both VWs and immersive VR systems, and thus it is usually confusing (Sherman & Craig, 2003). Throughout the paper, terms virtual learning environment (VLE), educational virtual environments (EVE), VR application or system will be used interchangeably, as many authors name such systems differently, generally implying the same.

2.2 Virtual Reality in Education and Learning

The idea of the use of VR in educational purposes has been introduced since the very beginning of the VR era. The technology gives the possibility to train skills in a safe and interactive environment, allowing to recreate the real word authentic situations or even to create new worlds and experiences. Taken together with the tendency for price reduction, it makes VR very attractive for extensive use in learning. The students' attitudes and impressions from VR as an educational medium are generally highly positive. Still, there is an open question whether this is due to the tool's inherent characteristic or because of the novelty effect for learners, which is however beyond the scope of the paper.

It has been argued that because of its advantages VR environments can support and be used for any disciplines at any educational stages (Mikropoulos & Bellou, 2010). On the contrary, Dalgarno and Lee (2010), when identifying five main learning affordances of the use of VLE, noted that the connotation of the word *affordance* does not imply that VR in learning per se *will* facilitate learning:

- Based on the three-dimensionality of the environment and the possibility to explore it from various perspectives dynamically and interactively, it can facilitate the development of spatial knowledge in the domain explored.
- Based on the possibility to implement real or unreal situations, a VLE could be used for experiential learning in the domains that are impractical or impossible to learn in real world (e.g. nuclear industrial trainings, space equipment reparation).
- VLEs with the high degree of personalization and learner's control over the environment, as well as high degree of realism, could contribute to the *flow* state (Nakamura & Csikszentmihalyi, 2014) and thus increase learner's engagement.
- Because the technologies can keep consistency with the real world and provide a certain degree of sensory realism, they can be used to aid the transfer of knowledge. This is possible because of the high contextualization of learning.
- VLEs provide excellent opportunities to serve as a mean for communication and collaboration. Collaborative tasks can be supported more effectively than is possible with 2D alternatives.

Several limitation factors are being named when discussing why VR still has no widespread use in education, despite its attractiveness; mostly factors associated with limitations of the technologies per se, including usability, graphics, realism, motion and recognition issues (Kavanagh, Luxton-Reilly, Wüensche, & Plimmer, 2016).

2.3 Previous Works

There are several related studies reviewed EVEs. Institutionally, the focus of the works is usability, learning theories and learning outcomes. Mikropoulos and Natsis (2011) conducted a review of over 50 papers (1999–2009) concerning the use of VR and its features when designing and exploiting EVEs. Besides, they found that only a minority of the reviewed studies considered an exact underlying pedagogical theory. Duncan, Miller, and Jiang (2012) proposed a taxonomy of VWs usage in education based on dimensions of population, educational activities and learning theories, as well as technologies, reviewing over 100 paper. Identifying current research and practice directions, they also named relevant aspects for further research, among them accessibility and evaluation issues. Work of Kavanagh with colleagues (2017) concerned with the use of VR in education and reported underlying pedagogical motivation. Given rapidly growing research on the matter and continually evolving technologies, as well as being motivated by the need for the multi-purpose and comprehend taxonomy, the systematic review of papers published 2014–2018 was conducted, with a focus on the classification of EVE features, including the most recent trends uncovered by previous researches, such as 360-degree VR.

3 Methodology

The review was carried out following the logic of Webster and Watson (2010) and the aspects highlighted by Vom Brocke, Simons, Niehaves, Riemer, Plattfaut, and Cleven (2009). This review considered full-length articles in English in scientific journals, proceedings of international conferences, symposia, and workshops, published during 2014–2018 (as of November 2018). The period was restricted by this span as VR has become mainstream and the number of articles on the topic increases dramatically every year. An article was included if it contained a classification of VR based solutions in the educational context or at least two categories of VR and related features, considering interdisciplinary view. Potentially every paper contained different categories of VR related features or being possible to inspire the relevant classification were considered as eligible for the review. The focus was specifically on classification schemes because the approach allows to access and summarize information in an efficient and timely manner and enables identification of blind spots. To capture as many relevant papers as possible, the broad definition of VR and all VR sets without restricting input/output peripheral form were considered. As classifications of VR solutions can be considered as highly creative and original product, no attention was paid to the quality of the studies, which means that ‘grey’ literature potentially could be included in the scope of the review.

The search was conducted in ACM Digital Library, Wiley, ScienceDirect, and EBSCO Services. The search strings (SS) and results are summarized in Tables 1 and 2.

Table 1 Search strings

N	Search field	Search string	Hits
1	Abstract	(Virtual reality OR VR) AND (learning OR education) AND (classification OR taxonomy OR typology OR types OR categorization OR categories)	377
2	Abstract	(Immersive OR immersion OR 360) AND (learning OR education) AND (classification OR taxonomy OR typology OR types OR categorization OR categories)	387
3	Abstract	(Virtual reality OR VR) AND (learning OR education) AND review	282

Table 2 Search strings results

	Database	SS1		SS2		SS3	
		Hits	Initial selection	Hits	Initial selection	Hits	Initial selection
1	ACM DL	135	1	16	0	65	0
2	EBSCO	136	3	239	1	133	2
3	ScienceDirect	61	5	60	0	61	1
4	Wiley online	45	2	72	0	24	0

After screening search results using the first string, the second SS focusing specifically on immersive VR was created (as SS1 resulted in papers dealing with non-immersive forms of VR). Unfortunately, the string brought just one eligible paper above already identified ones. The SS3 was included to broaden the search results and include papers that do not have a classification per se but can inspire its creation later. The string gained three more papers for further review after abstracts screening. Nine additional papers were also added into the analyzed pool using additional sources (back- and forward search, without timeframe restrictions), resulting in 24 papers total. 17 of them were selected for the final analysis after reading the whole paper.

Articles were excluded based on the following exclusion criteria:

- The article contains no categories or types of VR solutions or VR related features.
- The classification is domain-specific and could not be generalized.
- The article is impossible to retrieve due to restricted access or the authors have not shared the article.
- The article language is not English.

4 Findings

17 articles were analyzed in terms of bases, subcategories, and purposes of the classifications. An overview of themes addressed in classification bases is given

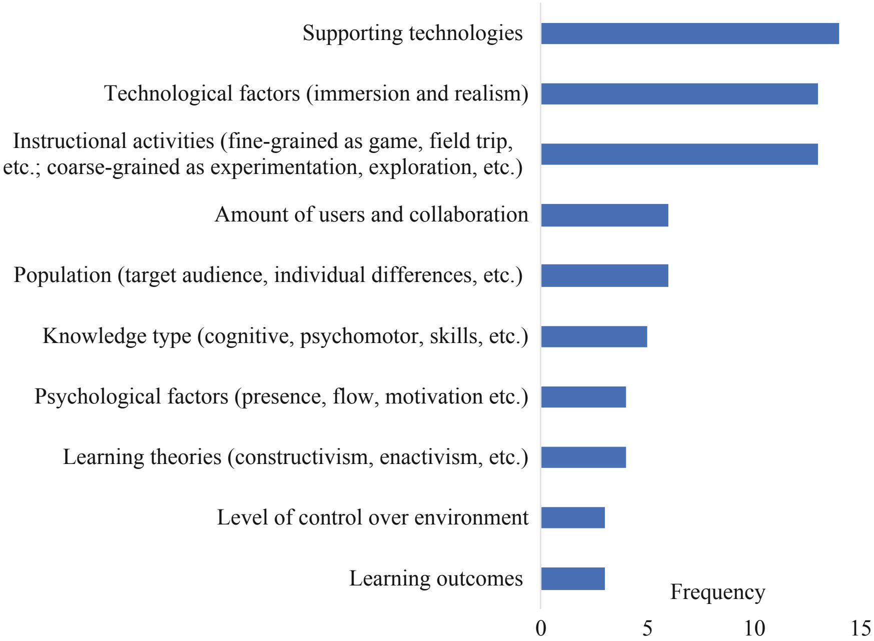

Fig. 1 Themes of classification dimensions, frequencies

on Fig. 1. The categories could be raised more than once in the reviewed papers. Some of the authors could base a single classification scheme on two and more themes concurrently (as, e.g. Elvestad (2016) addressed immersion level based on input/output peripherals), so they were counted as 2 and more categories.

The most common theme addressed in the reviewed classification schemes was technology-related aspects: e.g. type of VR devices and peripherals; and associated factors such as immersion and realism (representational fidelity). The authors deliberately separated technology-related immersion and psychological sense of presence into different categories. About as often was the category of instructional activities, on both levels: fine-grained types as educational games, field trips, role plays, and coarse-grained purposes of the activities, such as drill and practice, collaboration and communication, exploration and experimentation.

Based on the categories used, the taxonomy was based on the following dimensions: user (learner), context of learning, pedagogy, learning content, and technologies (Table 3). Because every subcategory breaks down into smaller subcategories, and each of them is a broad field for research [see, e.g. the extensive systematic review of locomotion techniques by Boletsis (2017)], a general overview with coverage of selective subdimensions will be discussed. Analysis of classification schemes considering the proposed taxonomy is given in Table 4.

Table 3 Taxonomy dimensions with subcategories

User characteristics (target audience factors)	Pedagogical factors (instructional decisions)	Learning content	Technology-specific factors	Context
Prior knowledge VR experience Computer literacy Learning preferences Age and cognitive characteristics Personal and socio-emotional characteristics (fear of height, special needs, etc.)	Learning theory Instructional activities and techniques Learning goals and objectives Level of guidance Learning feedback, etc.	Reality reflection and authenticity Knowledge type and skills focus Type of the learning content (domain specific focus, e.g. surgery simulation), etc.	VR sets, peripherals, and associated with them immersion level Navigation Manipulation Embodiment System feedback Portability (tethered), etc.	Educational context (e.g. academic learning, vocational learning) Physical context of learning (e.g. sitting, standing) Social context (n of users and agents) Reasons to use, etc.

5 Discussion

The results of the review suggest that the phenomena under consideration are versatile and could be addressed from different perspectives: learner, learning context, pedagogy, technology, and learning content.

Learner. The learner characteristics is a well-known concept used in the learning sciences to define those their aspects that could interact with the content, way, and result of learning (Drachsler & Kirschner, 2012). The concept of user characteristics, contrarily, is broader and used more frequently, and generally designate formal characteristics of the target audience. This category is delineated as the separate from pedagogical dimension to emphasize its importance not only for instructional designers but also for technological and other design decisions. Besides apparent attributes, Drachsler and Kirschner (2012) described academic (learning goals, prior knowledge, characteristics of curriculum), social/emotional (individual, e.g. sociability, self-image; as well as group characteristics, e.g. group structure, attraction networks, shared identity), and cognitive (spatial abilities, cognitive flexibility, attention span, intellectual skills, etc.).

Different users (e.g. children, aged, novices, experts) can also differ in their level of familiarity with technologies, openness to a new experience, motivation, pace of learning and level of guidance they need.

Pedagogy. This category is extensive and includes many subcategories. Learning theories, e.g., provide a robust and over-riding theoretical framework, predetermining the nature of the relationship to the learner and learning process in general. The most common approach to theoretically ground and support learning in digital

Table 4 Content analysis of classifications reported in the reviewed papers

Papers	User	Context	Pedagogy	Content	Technology
Duncan et al. (2012)	Age, special needs	Educational context	Learning theory, instructional activities		Navigation, immersion, controllers, Communicat. means
Elvestad (2016)		Number of users	Learning theory, objectives	Knowledge type	Hardware, software, immersion
Fowler (2015)		N of users	Learn. outcomes, Instruct. activities	Authenticity	Feedback, fidelity, embodiment
Girvan (2018)		N of users, reasons			Embodiment, Commun. means
Hew and Cheung (2010)		Reasons			
Hou et al. (2017)	Learner types			Knowledge and skills types	
Izard et al. (2018)				Realism	3D technologies
Jensen and Konradsen (2018)				Skills types	
Kavanagh et al. (2017)	Personalization	Educat. context, N of users, reasons	Learning theories	Domain	Feedback, peripherals
Li et al. (2018)		N of users			Peripherals, immersion
Mellet-d'Huart (2009)			Learning theories, Instruct. objectives	Domain, realism	
Menin et al. (2018)	Learner types	Reasons	Learning feedback		Peripherals, immersion, interaction, sensory feedback
Merchant et al. (2014)				Realism	Immersion

(continued)

Table 4 (continued)

Papers	User	Context	Pedagogy	Content	Technology
Potkonjak et al. (2016)		Educat. context, N of users		Authenticity, realism	Immersion, 3D technologies
Ángel Rueda et al. (2018)			Instruct. activities, objectives	Realism	Immersion
Schmeil and Eppler (2008)			Instruct. activities		3D technologies
Suh and Prophet (2018)	Individual differen., cognitive reactions				Peripherals, immersion

realities is constructivist theory, which posits that learners are active participants of learning (Onyesolu, Nwasor, Ositanwosu, & Iwegbuna, 2013), contrary to behavioristic approaches, which, for the most part, imply that the learning is the result of outside intervention. Highly interactive environment affords the essence of constructivist philosophy: construction of knowledge through experience and activity. Level of guidance or amount of control over the environment and the learning is another factor where there is a distinction between various VLEs, though generally it can be derived from the theoretical framework. Duncan et al. (2012) proposed a continuum to theories ranging from students passive engagement to active student engagement. Research suggests that activities allowing students to control their environment, learning pace, content, sequencing and amount of practice lead to better outcomes not only in learning content, but in general to improved self-concept (Kinzie, Sullivan, & Berdel, 1988; Zimmerman, 2002). However, this also depends on the content and general purpose of the environment. Weise and Zender (2017) classified VR educational worlds based on the interaction possibilities (*here*: level of control):

- Exposition world
- Exploration world
- Training world
- Construction world
- Experimentation world.

Learning content. Regarding the realism level, an obvious solution would be to divide VLEs into highly and lowly realistic environments. Mellet-d'Huart (2009) proposed to divide fields of study based on their "near-naturalness." The first category constitutes realism-crucial fields, needed to be recreated as they provide a safe place such as medical, driving, piloting, maintenance simulators, etc. The second category encompasses fields in which real aspects cannot be perceived as they are or needed to be modified in order to better suit learning aims (architecture, nuclear industry, medicine, biology, physics, etc.). The third category was not explicitly presented as realism related but based on the classification logic one can derive it as fields that do not require to be realistically presented, as, e.g. soft skills trainings.

Technology-specific. Technology-specific dimension includes usability and interaction factors as well. E.g. a decision on locomotion techniques in a VR environment should not be a random choice. Aside from usability issues (e.g. motion sickness), this decision should be highly relevant for the learning goals and learning content. In some cases, the use of relevant locomotion technique will help to better transit to the immersion state, essential for the optimal use of the medium. In some of the cases, it could be preferable to intentionally not to target the locomotion choices when it could hinder the learning processes. Boletsis (2017) in his review identified the main types of locomotion in VR: room scale-based, motion-based, controller-based and teleportation-based, which in turn fall into 11 VR locomotion techniques. Related to preceding discussed realism, Nabiyouni, Saktheeswaran, Bowman, and Karanth (2015) compared high-fidelity (realistic, as real walking), middle- and low-fidelity locomotion techniques, and concluded, that moderate interaction fidelity navigation lags behind hi-fi and well-designed lo-fi locomotion. However, the final decision should have regard to the learning content: psychomotor activities that are the primary goal of the learning process needed to be implemented with high fidelity.

Context. The category of context includes all the other decisions behind the design of learning environments, such as motivations of stakeholders (e.g. increase motivation), reasons behind (access limited resources, simulate a dangerous process, etc.), how the environment is supposed to be used (remotely, blended into curricula, individually or with others). Approach to divide environments into single- and multiple user's environments, showing how many people can interact with a VR system at a time, is not new. Indeed, possibilities to use VR as a tool for communication and collaboration are tremendous (e.g. Greenwald, Wang, Funk, & Maes, 2017). However, it is reasonable to also include non-human agents into this category. The reason behind the decision is a sense of so-called social presence, a socio-psychological phenomenon, which can be invoked not only by knowing that somebody is watching and co-present with one, but also simply by the reason that something is human alike (Nowak & Biocca, 2001). Social presence can be favorable for the sense of immersion, and thus for learning. However, social presence can also affect the performance and be a source of additional anxiety. In a sense, the believability of such experience makes VR also a great medium to train social skills and overcome, e.g. fear of public speaking (Anderson, Zimand, Hodges, & Rothbaum, 2005).

The notable result of the analysis is the fact that much attention is paid to technological aspects. However, now it is clear that attending the user—the learning human—and its needs and characteristics might be overlooked. This is not generalizable to the whole population of VLEs, as considering demographic and key characteristics of the target audience of such systems is a common practice when designing applications. Nonetheless, no explicit calls and precise recommendations are being made and empirically supported in scientific literature.

There is a strong need for guidelines and best practices for designing VR learning applications (e.g. Fowler, 2015). The proposed taxonomy could raise relevant research questions across disciplines: e.g. which supporting technologies are better fit different target audience and pedagogical approaches; which kind of locomotion is appropriate for different instructional activities and learning outcomes. The authors reckon that the taxonomy will help practitioners to consider a class of VLE in its diversity rather than focusing on a single solution. The taxonomy could also contribute to foreseeing new trends in research. It can also serve as a framework for the analysis and development of applications. Potentially it can also be generalized to other than education areas.

The present work is not the first attempt to provide a taxonomy of learning with VR, yet the most holistic and recent endeavor. Previous attempts considered only non-immersive forms of VR or were concerned with certain aspects of the medium (Mikropoulos & Natsis, 2011; Duncan, Miller, & Jiang, 2012; Kavanagh et al., 2017). The analysis showed that reviewed classifications partially selective, overlap and do not follow consistent terminology.

The present review has its limitations. First of all, many valuable phenomena relevant and generalized to the scope of the VR could omitted due to deliberate confine of the review to the field of learning. E.g. the field of locomotion research is a narrow and specific issue, not specifically explicit to the learning, but its specific design solution could potentially affect the usability of the implemented system and indirectly influence the learning outcomes. This relevant construct was not identified through the systematic review. On the other hand, there are many considerations relevant to the learning and instructional design in general, extraneous to the digital realities. Among them are, for instance, learning feedback and instructional objectives.

Another limitation is that the study employs a broad perspective, covering the phenomena from a broad angle and shallow depth, specific research topics were not addressed to the fullest extent. Besides, it is particularly challenging to make the categories exclusive, as they are highly interconnected. It also should be noted that the present review is not a review based on analysis of available and reported solutions, rather a synthesis of synthesized knowledge. The primary rationale behind that is to cover as many as possible instances, that could not be captured by a review of current use cases. The authors of the reviewed papers and classifications did not necessarily target the systematic taxonomy of VR learning phenomena. Though some identified categories were not included into authors classification, they were reflected as, e.g. advantages of using VR for learning (e.g. VR as a real-world substitute in Elvestad (2016)).

6 Conclusion

The article summarized a review of educational VR and the classification of its solutions in particular. After discussing vital elements and definitions of VR, the taxonomy of learning VR phenomena was introduced. It is based on five separate and yet intertwined dimensions: user, context, pedagogy, technology, and content. Classifications of pedagogical aspects and technology-related features were the most raised on the analyzed papers, whereas the learner related characteristics and types were rarely referred when categorizing virtual reality learning environments. Yet they could be considered when designing appropriate educational solutions, the need for it is very implicit and not systematically lit up in the literature. The authors believe that the approach more skewed towards cross-disciplinary collaboration will systematically and holistically explore raised questions and facilitate the establishment of solid guidelines for practitioners. A further work to refine and expand the proposed taxonomy is needed.

The proposed classification could serve a basis for analysis of state of the art of the VR solutions. With changing dynamics of the phenomena, it can also capture the versatility of developing and envisaged applications. This could also help practitioners to choose a design approach to VLEs and can be extended beyond the educational context.

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AR and VR in Tourism, Museums and Events

Teaching VR in Higher Education with Collaborative Projects

Lars Brehm, Marion Rauscher and Andreas Humpe

Abstract This paper presents a didactical concept to introduce students from various disciplines to digital technology and specifically to Virtual Reality technology. The concept is embedded into a constructivist learning environment to increase active involvement, self-directed learning and eventually motivation of students. Furthermore, it is based on a homogenous introductory framework in order to allow for a common knowledge baseline for the subsequent discovery learning within diverse contexts. Two applications are presented: a university teaching module in tourism management as well as in business administration. First qualitative and quantitative evaluations of the concept show positive results not only with regard to knowledge acquisition but also in terms of social, emotional and active involvement of students.

Keywords Virtual reality · Constructivism · Makerspaces · Higher education · Collaborative projects

1 Introduction

The labour market worldwide has been and will be changing rapidly. Especially new technologies are disrupting the current job market. Furthermore, a changing way of working caused for example by flexible work assignments, the rise in population paired with demographic change, climate change and dwindling natural resources, rapid urbanization and increasing social and cultural diversity also contribute to it (World Economic Forum, 2018). As a consequence, students have to be equipped with noticeably different competencies today than only five years ago, if they want to perform on the international labour market. When looking at skills forecasted to be

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needed in the international job market by 2022, analytical thinking and innovativeness as well as active learning and the development of learning strategies are among the top 10 (World Economic Forum, 2018). It is therefore necessary to expose students to an environment where they are able to acquire such skills. This way they will be able to continuously adapt to changing requirements or even to drive developments forward themselves early on.

Yet, the biggest disruptor is the technological change. It manifests itself in the increasing importance of technology design and programming or system analysis and evaluation competencies. At the same time, however, skills such as creativity, originality and own initiative, critical thinking, leadership competence or emotional intelligence, i.e. those skills which in contrast to the above-mentioned ones emphasize the human element, are equally part of the top 10 list. Purposeful teaching needs to translate all of these elements into an adequate didactic concept in order to prepare students for the working environment of tomorrow. A concept which optimally combines all of these elements is the constructivist learning theory.

The following article takes up the fastidious field of teaching these 21st century skills to University students. More precisely, it gives an introduction to teaching new technologies, with a focus on VR and its applications, embedded into a constructivist learning environment. The article is structured as follows. Chapter two will elaborate on the learning theory of constructivism as the basic concept behind the following teaching applications. An approach at the Munich University of Applied Sciences which serves as introductory course to teaching various digital technologies, is explained in Chapter three. This so-called "Learning Lab" and the herein specifically considered 360° VR stream is a generic approach which is why it can be deployed within various contexts of multiple disciplines as examplified in Chap. 4. The article concludes with further improvement and research considerations.

2 Constructivist Learning Theory

In the constructivist view of learning, knowledge and meaning is constructed from experience (Bruner, 1961; Piaget, 1929; Von Glasersfeld, 1982, 1989; Vygotsky, 1987). Learners are active creators of their own knowledge and in order to learn, they must ask questions, explore and assess what they know. As stated by Gil-Pérez et al. (2002): "[…] the constructivist approach in […] education is a proposal that contemplates active participation of students in the construction of knowledge and not the simple personal reconstruction of previously elaborated knowledge, provided by the teacher or by the textbook". With clear goals and limited information, students should have the best opportunity to construct knowledge (Kirschner, Sweller, & Clark, 2006; Steffe & Gale, 1995). Consequently, there is a shift from teaching a discipline as a body of knowledge towards learning a discipline by experiencing the process and procedures of a discipline (Handelsman et al., 2004; Hodson, 1988). Learning by experiencing the processes of a discipline leads to practical or project-based work. In addition, learning is seen as idiosyncratic and a common instructional

Table 1 Constructivist learning process (based on Reinmann-Rothmeier and Mandl (2001))

Process	Description
Active	Knowledge is only acquired through autonomous and active participation
Constructive	Knowledge is only acquired when build into existing knowledge and can be interpreted on individual's experience
Emotional	For knowledge acquisition to happen, positive emotions are crucial
Self-directed	The learner must control and monitor own learning process
Social	Acquisition of knowledge occurs through interaction with others
Situative	Knowledge acquisition is tied to a specific situation or context. Learning always takes place within the context of a specific learning environment

format is therefore ineffective. Thus, teaching based on constructivism needs specific teaching practices that facilitate the construction of knowledge individually.

According to Reinmann-Rothmeier and Mandl (2001) the learning process from a constructivist perspective is characterized by the six aspects of an active, constructive, emotional, self-directed, social and situative process (Mandl & Kopp, 2005) (Table 1).

When implementing constructivist principles into teaching several typical instructions can be followed, among others discovery learning, peer-assisted learning and discussions (Schunk, 2012). In discovery learning, lecturers set up activities in which students explore problems by themselves and therefore acquire knowledge on their own (Bruner, 1961). It provides an inductive learning environment with marginal guidance by lecturers. Discovery learning is only suitable, however, when students have prior experience or background information on the studied subject (Tuovinen & Sweller, 1999). Peer-assisted learning includes cooperative learning, where students work in groups on a common final goal, as well as peer tutoring. The latter refers to students tutoring each other rather than having lecturer-student instructions. Lastly, discussions are helpful to add different perspectives to a certain subject and to gain a common understanding. As self-directed construction and reinforcement of knowledge works remarkably well in makerspaces, where students create and share objects and digital fabrications, the situative process can be implemented by the use of pop-up makerspaces (Wong & Partridge, 2016).

3 Learning Lab 360° VR Collaboration Stream

3.1 Learning Lab Didactic Concept

The Learning Lab "Digital Technologies" (www.LL4DT.org) serves as a new teaching approach at the Munich University of Applied Sciences and beyond, picking up the constructivist learning elements. In this lab students can, through concrete small projects, familiarise themselves with digital technology and its possibilities—without becoming "too technical". This foundation is the basis for own applications in areas of virtual and augmented reality or other areas like data mining, industrial internet or smart mobility.

In the Learning Lab, student teams are being challenged to use hard- and software through the autonomous work on exercises or small sample projects, the so-called assignments. Quick wins motivate the students to independently deal with and solve follow up exercises. The lecturers are predominantly there as coaches. The assignments are concluded by reflection work and "lessons learned" elements. To carry the course through, the Learning Lab is set up as a pop-up makerspaces (Brehm et al., 2019). The mobile set up allows it to be installed temporarily in an event room, situating it where students are, rather than a permanent space waiting for learners to come (Wong & Partridge, 2016). The Learning Lab is geared to offer several digital technologies—these are different one-day respectively two-days-workshops, the so-called streams. Lecturer utilize one or more of these workshops in their regular course. All streams are based on the utilisation of available, inexpensive and expandable standard components. An overview of the currently available streams is shown in Fig. 1. Additional streams can be added easily.

Fig. 1 Available streams of the learning lab

Table 2 Implementation of constructivist learning at learning lab "digital technologies"

Process	Implementation
Active	A final goal is set for each assignment and practical tasks incl. hands-on activities with digital technologies must be accomplished. Students work autonomously
Constructive	During an assignment knowledge is provided on the spot for a practical task or must be researched by the students. Each assignment contains retrospective questions at the end to reinforce the learning process. An upfront quick introductory lecture on the domain for framing and follow up usage of knowledge in the remaining part of course
Emotional	No marks for the work reduce negative stress and a feeling of success induce positive emotions (for the learning lab)
Self-directed	There is no fixed schedule, student teams work self-paced. Student can select parts from the assignments to dig deeper
Social	Collaboration and problem solving in students' teams
Situative	Regular, familiar seminar rooms are utilized for the learning lab. Lecturer acts as coach and helps just on request. The context of the assignments is based on a practical problem to be solved

The Learning Lab's concept also includes the active creation of a community of lecturers, who develops the Learning Lab content-wise as well as technically and also gives access to numerous students coming from different study areas. The community includes professorial colleagues at the Munich University of Applied Sciences who face a similar challenge across different departments as well as an inter-university community across Germany and Europe. Benefits for the colleagues are: a finished and tested didactic concept, short preparation time and—if required—fast adaptability. Table 2 shows how the elements of the learning lab approach fits to the constructive learning approach.

3.2 360° VR Collaboration Stream

The 360° VR Collaboration stream has been executed several times in different faculties as the technology is experiencing strong growth. Yet, still emerging, it already offers several application possibilities in the industry as well as in the academic field. Turnover with VR-hardware and—content is forecasted to reach €1bn by 2020 in Germany alone and $10bn by 2021 worldwide (Statista, 2019a, 2019b). Product development prototyping, immersive experiences in the entertainment industry or creating new learning and collaboration environments are just some of the potential areas of use (Kugler, 2017; Ma, Gausemeier, Fan, & Grafe, 2011).

The used technology in the 360° VR Collaboration stream includes Samsung Smartphone and Apps, Samsung Gear VR Headset and Samsung Gear 360° camera since it is quick to implement and easy to use. Currently there are 11 assignments shown in Table 3, with which students are challenged to deal with the respective hard- and software. Each assignment comprises between two to 8 pages allowing for different degrees of difficulty. This leaves room for students to vary the level of detail of solution guidance and steps according to their individual preferences. All assignments conclude with a reflectory phase.

Table 4 shows the evaluation (n = 48) of the Learning Lab VR 360° based on the 6 constructive learning processes by Reinmann-Rothmeier and Mandl (2001).

Before the learning lab, only one third of the participants stated a good knowledge and understanding of virtual reality. However, after the learning lab, the agreement rate of the statement increased to more than 95% and supports the successful knowledge acquisition by our didactic concept. Furthermore, students rated the learning lab 360° VR as highly social, emotional and active. Working actively together to solve the assignment tasks seems to motivate and engage students and induces positive emotions. However, in comparison the ratings for situational, constructive and self-regulated are much lower. As students only work on rather small practical tasks, they were not convinced to learn something for real life. The fixed structure of assignments and tasks reduced the freedom to decide about the learning subject. This might explain the low reading on the scale self-regulated. Finally, students were not always able to build upon existing skills and knowledge. To overcome the shortcomings of the learning lab we propose to complement it with a real project case study. When students work in groups on a real project, they should see the relevance of the work for real life. In order to make it self-regulated, students must have a high degree of freedom in the case study to decide on how to archive a final task. During the case studies, students should get occasional training by industry experts and short lectures to be able to better build on existing knowledge.

Table 3 Assignments of 360° VR collaboration stream

Number	Title
1201	Watch virtual reality video
1202	Assemble camera equipment and connect App
1203	Shoot first 360° video and watch it
1204	Stitch video and watch video on computer
1205	Watch virtual reality video (via file transfer)
1206	Edit 360° video
1207	Shoot second 360° video, edit and watch
1208	Best practices for shooting and editing
1209	Create team 360° video presentation
1210	Legal compliance check with upload of 360° video presentation
1211	Share team 360° video presentation

Table 4 Evaluation results of 360° VR collaboration stream

Scale	Question	Agree (%)	Not agree (%)
Social	I worked constructively with others while learning	98	2
	I exchanged ideas with others while learning	93	7
	I learned together with others	95	5
	Total social scale	95	5
Constructive	I was able to build on existing knowledge	64	36
	I was able to draw on existing skills	54	46
	I was able to connect new knowledge with what I already know	64	36
	Total constructive scale	61	39
Emotional	I was keen on learning	85	15
	I had fun learning	91	9
	I felt good during learning	90	10
	Total emotional scale	89	11
Self-regulated	I could decide the learning subject myself	77	23
	I could decide for myself with what I learn	53	47
	Total self-regulated scale	65	35
Active	I was eager to learn	85	15
	I was active during learning	89	11
	Total active scale	87	13
Situational	I learned something I can use in everyday life	42	58
	I learned something I can make good use of	48	52
	I learned something that helps me in real life	47	53
	Total situational scale	46	54

4 Application of Learning Lab 360° VR in Combination with Case Studies in Teaching Modules

4.1 Module in Tourism Management

Within the tourism sector VR-technology is also increasingly becoming popular and fields of application are manifold (Guttentag, 2010). So far, the most researched application is the marketing of destinations with VR. The technology can help reduce the uncertainty associated with buying a touristic product. The "try-before-you-buy" option helps the traveller to get a more realistic experience of what to expect. Tussyadiah, Wang, Jung, and tom Dieck (2018) found, that the feeling of being in a virtual environment creates a positive sensation for the potential tourist, which leads to a stronger preference for the destination and ultimately a higher likelihood of visiting the destination. Since its application is becoming more and more widespread it is sensible to engage students of the tourism subject with the use of the technology within a constructivist learning process.

In order to deploy the situative element of the constructivist learning approach, the learning lab was supplemented with a specific applicational context which allows analysing the subject from a different perspective. Within the scope of a practical project students of the Faculty of Tourism of Munich University of Applied Sciences were to get familiar with VR technology and to explore its application in a touristic scenario. More specifically, participants of the module had the task to create a virtual tour of the Faculty with embedded information and short 360° VR video clips for potential new students. The goal was to convey relevant information, arouse study interest, reduce uncertainty regarding the selection of study location and, hence, increase the number of applicants. Participants were divided into groups of three and were assigned to spatially different zones. Each group was requested to assemble material within their spatial area. Plenary sessions in order to discuss and reflect project progress as well as to select and merge the single components took place on a regular basis. To start from a common base, students completed the 360° VR Collaboration Learning Lab in the first sessions. This set ground for the following discovery learning environment since Kirschner, Sweller, and Clark (2006) point out that minimally guided instructional approaches only work when students have sufficient prior knowledge. By subsequently embedding the Learning Lab stream into a new setting, students became actively involved in a topic of their interest and were required to manipulate the already reviewed material.

The active component in the proposed project was given extensive space as student groups worked completely autonomously on their assigned tasks. Although, the overall goal as well as a rough timetable was drawn, there was no guided in-classroom work. Students were able to freely choose which material to assemble and when. Nevertheless, regular meetings of the entire groups were scheduled to discuss plans, progress, problems and questions of the different teams. These plenary sessions ensured sharing of knowledge and lessons learned, thereby contributing to the social component in the constructivist learning environment apart from the separate groups' work. Although, guidance and support were given by the lecturers if needed, students worked generally self-directed. Even feedback was given mainly by peers to allow for socially mediated learning.

A generally challenging task is to arouse positive emotions in the teaching environment. Even though, those cannot be induced by the lecturer, several framework conditions of the conducted project point towards favourable sentiments. First, students can choose in which project they want to participate within the tourism curriculum of the Faculty. Therefore, a certain level of intrinsic motivation of the participants can be assumed from the beginning. Second, by using the VR Learning Lab as a starting tool, they were able to experience the technical issues from an entertaining viewpoint, which solicited positive feelings for the upcoming project work. Third, the prevailing multidimensional classroom (Schunk, 2012) allows for a high motivation. Especially giving students control over time management to lower work delivery pressure and to promote the use of self-regulatory strategies support this hypothesis (Schunk &

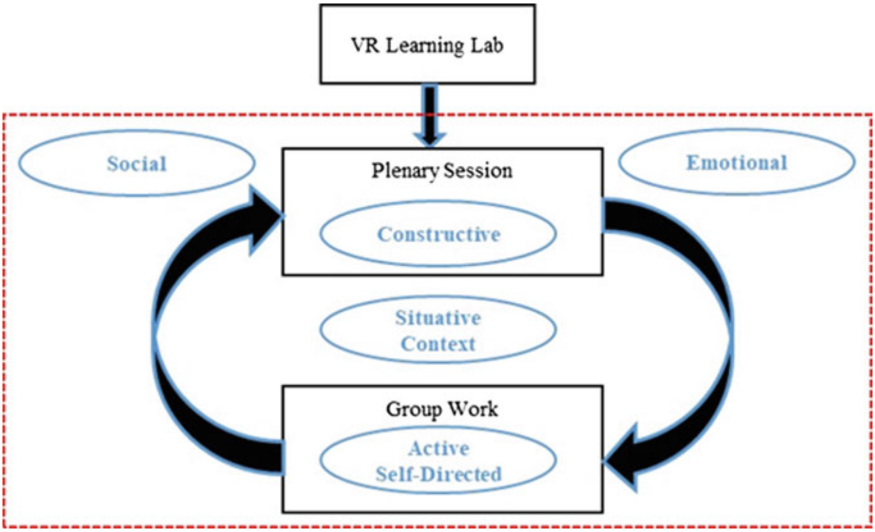

Fig. 2 Constructivist learning cycle of the module

Zimmermann, 1994). Fourth, the module is not graded. Assessment occurs continuously during plenary session and is rather a question of next steps towards a joint overall project goal. This shared project goal highlights the social environment as a facilitator of learning and improvement.

Figure 2 visualizes the learning cycle the participants went through during the course of the project as often as was necessary. The cycle establishes the necessary balance between instruction and construction as demanded by Reinmann-Rothmeier and Mandl (2001).

During the project phase, an evaluation by the students took place in order to implement improvement suggestions while still in working progress. Items with the highest consent included "The project is interesting for me", "The collaboration with my team members contributed to the successful outcome of the project" and "Participants were given much freedom when conducting the assigned tasks". Overall, it appears reasonable that real project case studies complement the Learning Lab quite well and improve the learning outcome.

4.2 *Module in Business Administration*

Another application of the Learning Lab took place at the Faculty of Business Administration at Munich University of Applied Sciences. The teaching concept presented in the following section provides for the support of collaboration in distributed, virtual project teams using VR technology as a deployment scenario. This is intended to create a realistic and practice-relevant working environment for the students in which they can directly test and experience the application of the VR technology they have learned.

Everyday work is increasingly characterized by collaboration in distributed, virtual teams. Essential drivers for this are the functional and global distribution of companies across different locations as well as the change of the workplace to a location-independent, digital workplace (Crowston, Sieber, & Wynn, 2007; IDG Research Services, 2017; Kane, 2015).

Virtual teams are defined as "groups of geographically, organizationally and/or time dispersed workers brought together by information and telecommunication technologies to accomplish one or more organizational tasks" (Powell, Piccoli, & Ives, 2004). Information and communication technologies (ICT) play a central role here: they enable an effective exchange of information and coordination in virtual teams across spatial and temporal boundaries (O'Leary & Cummings, 2007).

Virtual teams are confronted with fundamental challenges due to the spatial and temporal distance. These challenges exist at the socio-emotional level in building relationships, cohesion and trust between team members. At the task level, the challenges lie particularly in the areas of communication and coordination (Powell, Piccoli, & Ives, 2004). These challenges are further reinforced in globally distributed teams due to cultural differences and the fact that virtual teams are often formed only temporarily for specific tasks or projects (Chase, 1999).

Due to these diverse challenges, the effective leadership of virtual teams to build trust as well as the management of virtual work processes is of crucial importance (Malhotra, Majchrzak, & Rosen, 2007). Through the use of VR technology, these practices can be meaningfully supported. 360-degree video recordings enable members of a virtual team to present themselves in their natural working environment and share task-related information (Kugler, 2017). These recordings can be viewed using VR technology. In this way, immersion in the environment of the other person is made possible, which leads to the formation of solidarity between the members in virtual teams.

In order to enable students to experience such an application of VR technology in collaboration in virtual teams, the teaching concept "360° VR Collaboration" provides for the processing of a task in virtual project teams. Student teams distributed across different locations are working on a joint project. In this setup, the use of VR technology to promote cooperation is to be tested. The students acquire the necessary technological competences by completing a learning workshop as part of a teaching module which will be illustrated in the following.

An international and interdisciplinary project collaboration between student teams at three university locations with the following responsibilities was implemented:

- Tampere University of Applied Sciences (TAMK), Finland: Technical development of a product innovation (prototype)
- Munich University of Applied Sciences (MUAS), Germany: Business Model Development
- University of Primorska (UoP), Slovenia: Customer Experience (Customer Journey & Touchpoints).

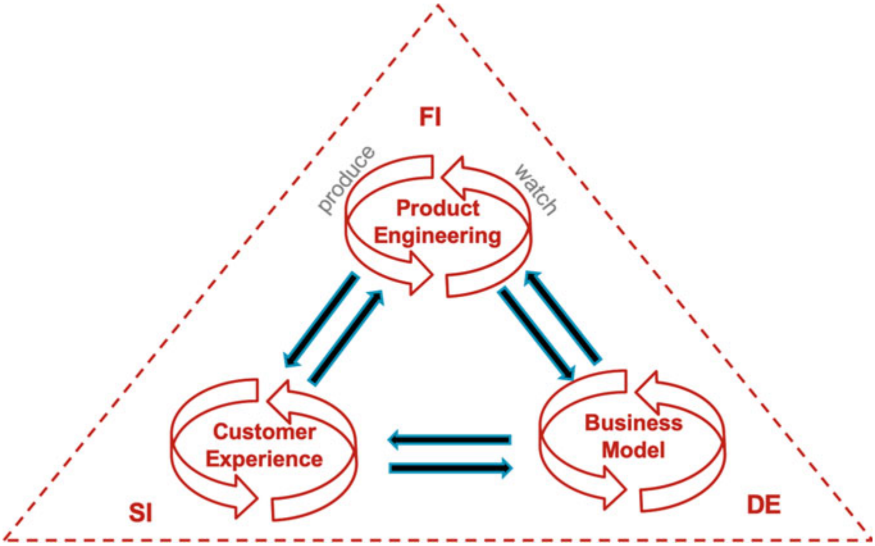

Fig. 3 Collaboration in the presented teaching module

The communication and exchange of information in the joint project was supported by the use of VR technology. The student teams at the three locations first completed the learning workshop "360° VR Collaboration". Subsequently, the teams produced their own 360° videos in three phases, which were used to introduce the team members and to exchange project results. The produced videos were watched (consumed) by the other teams with VR glasses. Figure 3 shows this exchange and the interrelationships between the teams.

The learning outcomes were continuously and conclusively evaluated both qualitatively and quantitatively. The qualitative evaluation included the creation of retrospectives, especially with regard to the production of own 360° videos. The experiences of the use of VR technology in international project collaboration were also recorded in the form of retrospectives with regard to the possibilities and limitations. The quantitative evaluation was carried out using a standardized questionnaire across the three locations. Based on these initial evaluation results, a scientific accompanying research concept for the learning workshop is to be developed and established.

5 Conclusion

Students have to be prepared to face the challenges of the 21st century. Digital literacy, collaboration skills and self-directed learning are competencies at the forefront of these required capabilities. In this article the "360° VR Collaboration" stream of the Learning Lab and its application in a constructivist learning environment was presented. In addition, the use of complementary real project case studies seems to further improve the learning outcome. The cases introduced proved to be an ideal setup in order to teach all of these 21st century competencies mentioned above in combination.

So far, feedback and evaluation by participants is favourable and points towards the effectiveness of the teaching setup. However, for research purposes a large-scale quantitative evaluation is yet lacking. Locking ahead it is therefore necessary to first refine the standardized questionnaire according to the qualitative results obtained. Second, the presented modules should be conducted and evaluated repeatedly in order to acquire a broader database which will serve as the basis for more quantitative oriented research. Third, it is advisable to deploy the Learning Lab stream in other settings as well. This will allow qualitative and quantitative conclusions with regard to interferences between different application scenarios within multiple industry branches.

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The Impact of Mixed Reality on Visitors' Experience in Museum. 'The Ara As It Was' Project in Rome

Mariapina Trunfio, Salvatore Campana and Adele Magnelli

Abstract Although new realities are receiving increasing attention in tourism, the effect of them on cultural heritage has still not been fully answered and research on this topic is still in its infancy. This paper aims to contribute to advances in research on visitors' experience analysis in museums, applying the Trunfio and Campana (Curr Issues Tourism 1–6, 2019) model for mixed reality in museums. The empirical analysis concerns 'The Ara As It Was', a mixed reality project installed in the iconic and historical Ara Pacis Museum in Rome (Italy). The findings, discussion and conclusion open new avenues of research and suggest managerial implications to improve museum competitiveness.

Keywords Mixed reality · Museum · Visitors' experience model · Visitors' satisfaction

1 Introduction

Cultural heritage organisations, including museums, are exploiting new reality opportunities to redesign their service models, creating an immersive site-visit and combining diverse experience typologies (Trunfio & Campana, 2019). Augmented and Virtual realities have transformed heritage museum in a smart place where drawn virtual maps, digital simulation and immersion, appealing graphics and audios, facilitate enjoyment and emotional fruition, reducing traditional barriers and enhancing information for non-expert visitors (tom Dieck & Jung, 2017). In this perspective, many museum are investing in new technologies with the main goals of enhancing

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the value of visitors' virtual experience (Fenu & Pittarello, 2018; Han et al., 2018; tom Dieck & Jung, 2017).

Although new realities are receiving increasing attention in tourism research and cultural heritage (Guttentag, 2010; He et al., 2018; Jung et al., 2018; tom Dieck & Jung, 2017; Yung & Khoo-Lattimore, 2019), the impact of them on cultural heritage have yet to be fully answered and research on this topic is still in its infancy.

In a recent study, Han, tom Dieck, and Jung (2018) identified an user experience model, evaluating augmented reality applications in urban heritage tourism in terms of content, presentation, functionality and interaction. Building on the prevalent literature and Han et al.'s, model (2018), Trunfio and Campana (2019) propose a novel model that captures the impact of mixed reality on museum visitor experience and satisfaction. It designs a conceptual framework of seven dimensions and 23 items influencing human-technology interaction and experience in a museum.

This paper aims to contribute to advances in research on visitor experience analysis in museums, applying the Trunfio and Campana's (2019) visitor experience model for mixed reality in museums. The empirical analysis interests 'The Ara As It Was', a mixed reality project installed in the iconic and historical Ara Pacis Museum in Rome (Italy). Findings, discussion and conclusion open new avenues of research and suggest managerial implications to improve museum competitiveness.

2 Theoretical Background

New realities—including Augmented Reality (AR), Virtual Reality (VR) and Mixed Reality (MR)—have been receiving increasing attention in tourism and cultural heritage research (Guttentag, 2010; He et al., 2018; Jung et al., 2018; Yung & Khoo-Lattimore, 2019).

The literature identifies the concept of new realities as technologies redesigning the real-virtual continuum phenomenon, integrating reality with virtual space and providing multimedia representations of real-life and past and/or imaginative events (Yung & Khoo-Lattimore, 2019). AR embeds digital and synthetic multimedia information in real-life contexts, amplifying the degree of user information acquisition (He et al., 2018; Jung et al., 2015); VR promotes alternative world visualisation through different levels of immersion and interaction (Guttentag, 2010). Finally, MR represents a continuum immersive link in an environment characterised by virtual and real elements (Bekele et al., 2018; Milgram & Kishino, 1994).

AR and VR present differences in users' levels of both immersion and presence (Guerra et al., 2015; Guttentag, 2010; Jung et al., 2018; Wei et al., 2019). Indeed, with AR, users augment their own visualisation level of information while remaining in a familiar real-world through action-simulation. With VR, users live a multidimensional psychological illusion to participate in the virtual contexts, isolated from real world (Guttentag, 2010; Wang et al., 2018; Wei et al., 2019).

Museums represents one of the main areas of research preferred spaces in which analyse opportunities and risks of experiences under conditions of new realities. They create new elements supporting museum exhibitions—visualisation, immersion and interaction—redesigning the organisation of a cultural site-visit as an immersive experience in which firstly, experiential learning is combined with edutainment, secondly, heritage preservation is enhanced (Bec et al., 2019; Bekele et al., 2018; Guttentag, 2010; Han et al., 2013; He et al., 2018; tom Dieck & Jung, 2017; Trunfio & Campana, 2019; Yung & Khoo-Lattimore, 2019).

Their application introduces alternative scenarios of heritage exhibition management reinforcing the link between visitors immersive experience and the virtual interaction with cultural and historical artefacts (Bec et al., 2019). By facilitating integration between real and virtual settings, new realities ensure full visitor immersion and overall engagement in the museum experience (Trunfio & Campana, 2019).

Research on VR and AR in museums covers visitors' motivations, critical factors and benefits, and service features able to increase user intentions and their emotional experience (Del Chiappa et al., 2014; Guttentag, 2010; Poria et al., 2006; Rauschnabel & Ro, 2016; Trunfio et al., 2018; Jung et al., 2018).

Although such technologies present diverse opportunities, their application requires constant monitoring and testing of the latest solutions available on the market, in order to identify the strengths and weaknesses of diverse tools. User requirements, technology acceptance and intention (Chung et al., 2015, 2018; Han et al., 2018) are still considered to be the main challenges for scholars and museum organisations. The user interface should have a simple and authentic design giving prompt access to required information. It requires usability in order to provide an easy utilisation and an authentic experience. Information needs to be relevant and updated and the content communicated without difficulty. An important aspect is the size of the application, its speed and loading times. Social networking and reviewing are gaining importance. Efficiency and time saving is a key theme, as is ease of use.

A recent model of user experience for augmented reality in urban heritage tourism has been proposed (Han et al., 2018), identifying factors that influence AR acceptance and satisfaction, and improving the effectiveness of product features. It proposes applications in urban heritage tourism in terms of content, presentation, functionality and interaction describing product features.

Building upon relevant literature and Han et al.'s (2018) model, Trunfio and Campana (2019) propose a novel conceptual model capturing the value of mixed reality in a museum service model and its effects on visitor experience.

The Trunfio and Campana's (2019) visitor experience model for mixed reality in museums designs a conceptual framework of seven dimensions and 23 items measuring experience and satisfaction.

3 Case Study

'The Ara As It Was' represents a mixed reality project installed in the iconic and historical Ara Pacis Museum in Rome (Italy). It was developed by the Experience Designer ETT S.p.a., a company specialising in new technologies and multimedia

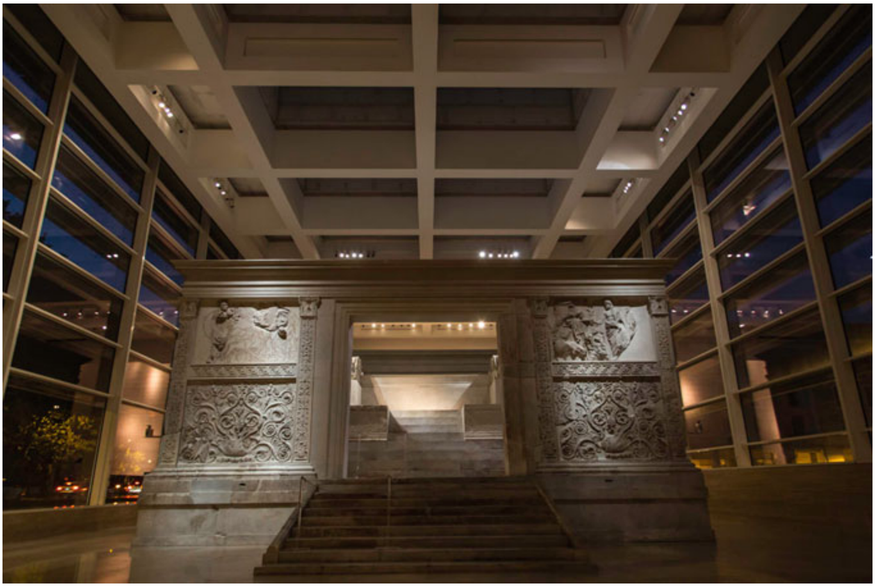

Fig. 1 The Ara Pacis Museum in Rome

tools, to enhance the value of the Ara Pacis monument, built between the 13th and 9th centuries BCE (Fig. 1). A 3D tracking system was applied to this project, making use of the most advanced computer vision algorithms.

The entire Augmented Reality system recognises three-dimensional bas-reliefs and carries out real-time tracking, increasing the effectiveness of this immersive experience.

The project was conceived for evening museum visits. Each visitor receives a Samsung Gear VR viewer that, combined with a Samsung S7 smartphone, shows not only Virtual Reality content but also triggers content in Augmented Reality. There are nine points of interest (POIs) along the visit route. Wearing Samsung Gear VR visors, spectators are greeted with a 360° video of the Ara Pacis as it is today, before finding themselves in a white space in which the monument appears in its original colours.

In the Ara Pacis project, the combination of the AR and VR enhances the user experience and give results to one of the most important monument's history, providing a hybrid approach experience to monument visitors.

4 Methodology

The Trunfio and Campana's (2019) visitor experience model, for mixed reality in museums (Table 1), was applied to 'The Ara As It Was', a mixed reality project

Table 1 The visitors' experience model for mixed reality in museums

Dimensions	Items
Museum information	Exhibition
	Service
	Historical period
	City attraction
Customisation	Personalised information
	Multiple language capability
Format	Audio
	Images and video
	Accessible using own mobile device
	Touch
Usability	Comfort
	Clever alternative to access information
	Easy to use
Information saving	On personal devices
	On museum platforms
Interaction	Museum servicescape
	Multimedia elements
	Other technologies
Experience	Heritage valorisation
	Educational
	Entertainment
	Socialisation
	Escape

Source Trunfio and Campana (2019)

installed in the iconic and historical Ara Pacis Museum in Rome (Italy). The project is regarded as an innovative space in which to test the model, using an empirical analysis in which mixed reality enhances the value of this historical monument, considered to be an important Roman artistic masterpiece.

The Trunfio and Campana (2019) model comprises seven dimensions and 23 items, integrating functional elements of mixed reality (six dimensions and eighteen items) and experiential elements (one dimension and five items) that measure the mixed reality effect on the visitor experience. Functional elements consider the following dimensions (and items): museum information (items: exhibition, service, historical period and city attraction), customisation (items: personalised information and multiple language capabilities), format (items: audio, images and video, accessible on personal mobile devices, and touch), usability (items: comfort, clever alternative to access information and easy-to-use), information saving (items: on personal devices and on museum platforms) and interaction (items: museum servicescape, multimedia elements and other technologies). The experience dimension considers items to be heritage valorisation, educational, entertainment, socialisation and escape.

The 18 functional items of the Trunfio and Campana's (2019) model was measured considering two sections for each item using a seven-point Likert scale: the first measuring the level of expectations (importance); and the second the level of satisfaction (performance).

The interviews were conducted at two separate times, before the visitor experience and after the visit, in order to evaluate the level of satisfaction/performance (seven-point Likert scale).

Data collection was obtained from July to December 2018, through face-to-face interviews in the museum and selecting 726 visitors with simple random sampling (Wang et al., 2012).

Data were analysed using the Statistical Package for Social Sciences 11 (SPSS). The importance and performance analysis (IPA), one of the most common methodological tools in tourism and service research (Lai & Hitchcock, 2015), revealed the strategic position of the 18 functional items of the Trunfio and Campana's (2019) model in a matrix measuring the level of importance and performance.

5 Results and Discussion

Findings allows to underlines how Italians represent the majority of visitors to the Ara Pacis Museum (65%) followed by foreign visitors, where the main countries are USA (7.7%), Germany (6.4%), Spain and UK (3.8%). Female visitors were 53.2% and the most representative age group was from 20 to 29 (23.1%), followed by 30–39 (21.8%) and 40–49 (19.2%). Visitors with a high level of education prevail (37.8% with a university degree) and the majority are either employees (38.7%) or students (22.6%).

Interesting results emerged when applying the importance and performance analysis on the Trunfio and Campana's (2019) model.

Visitors attributed a medium-high level of importance (seven-point Likert scale) to all items ranging from 4.82 (socialisation) to 6.54 (images and video).

The results showed a high level of overall satisfaction (5.36), confirming the effectiveness and innovativeness of the project. The satisfaction value ranges from 4.06 (touch) to 6.13 (multiple-language capability and audio).

Visitor expectations (importance) and satisfaction (performance) can be analysed considering two importance-performance matrices measuring the functional aspects of mixed reality in the museum (Fig. 2). They show the success of 'The Ara as It Was', a mixed reality project installed in the iconic and historical Ara Pacis Museum in Rome (Italy).

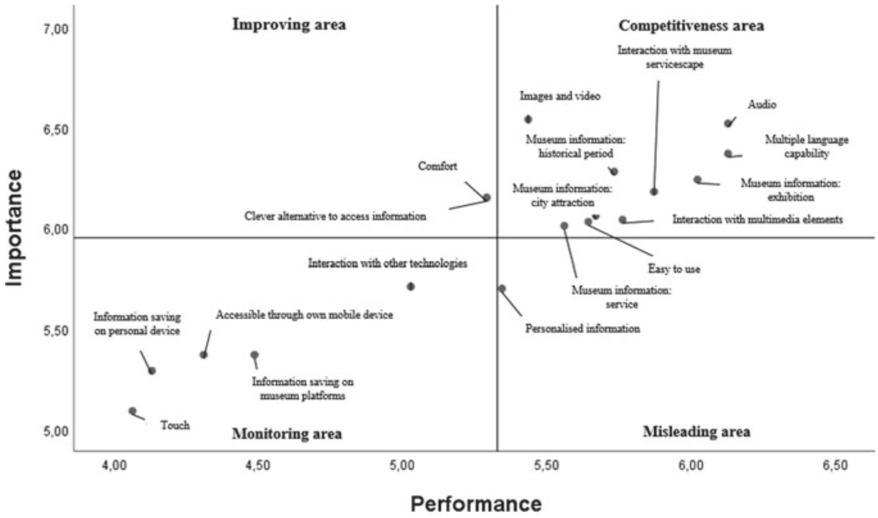

Fig. 2 Visitors' perception of mixed reality applications in the Ara Pacis Museum

Visitor perception of ten items describing mixed reality applications in the Ara Pacis Museum present a high level of expectation and satisfaction, covering the competitiveness area (Fig. 2).

The presence of ten items in the competitiveness area confirms the central role of MR technologies in creating innovative storytelling, content and knowledge, facilitating the museum visit and increasing visitor satisfaction.

Other interesting items in the quadrant of competitiveness are image, video and audio (format dimension), museum servicescape and multimedia elements (interaction dimensions), multiple language capabilities (customisation dimension) and easy to use (usability dimension). Their positioning in the quadrant of competitiveness shows how MR improves the active role of the visitor during the museum fruition, interacting easily with both the servicescape and multimedia tools.

Sophisticated audios, images and videos, in diverse languages, reinforce the visitor immersion state in the real-virtual landscape (Wang et al., 2018; Wei et al., 2019), allowing the process of service museum re-organisation towards new forms of experiences.

The monitoring area covers space in which the visitors position elements with a low level of both importance and satisfaction in an immersive museum visit.

Five items cover the monitoring area such as accessibility on own mobile device and touch (format dimension); other technologies (interaction dimension); and information saving on personal devices and on museum platforms (other dimension).

These results are coherent with the Ara Pacis Museum approach which does not allow the reproduction of MR technology on visitors' mobile devices. They consider that integration with other technologies and saving information or memories on smartphones or museum platforms are functions that reduce the immersive experience, distracting visitors.

The last three items cover unusual positioning. Although very close to the competitiveness area, the comfortable and clever alternative to accessing information (usability dimension) expresses visitor limits when wearing Samsung Gear during the visit to access alternative information. Similarly, personalised information (customisation dimension) covers the misleading area but is very close to the monitoring area. Improving the level of personalised information can represent a future challenge offering different levels of information through MR for both expert and general visitors.

6 Conclusion

Museums are exploiting new reality opportunities to redesign their service proposal and create unique experiences as an immersive site-visit, combining experiential learning with innovative forms of entertainment and recreation (Jung & tom Dieck, 2017; tom Dieck et al., 2018; Trunfio & Campana, 2019). Overlaying the physical environment with multimedia elements and digital content, they provide a multi-dimensional awareness in which the user's psychological presence and the immersion in a virtual landscape are combined with surrounding context, substituting or integrating the real experience of visitors (He et al., 2018; Wang et al., 2018).

'The Ara As It Was' is a successful combination of advanced technology and innovative storytelling increasing visitor presence and participation. The content is the core of storytelling, indeed the reconstruction of the original colours on the monument works as the storyteller, creating an immersive trail around it. This experience certainly marks a very important step in re-evaluating the role that new multimedia technologies have within the enhancement processes and the improvement of both content and research.

The research also confirms the new role of museums as an immersive culture site combining heritage elements with multimedia formats (He et al., 2018; Trunfio & Campana, 2019). By levering on mixed reality, 'The Ara As It Was' project innovates and reshapes the iconic and historical Ara Pacis Museum in Rome, creating an immersive site-visit in which the combination between experiential learning and entertainment enhances visitor presence and satisfaction. Although preliminary, this research confirms some theoretical and managerial implications but it starts to explore new areas for future research, as well as spaces enhancing innovation in technological tools. Some theoretical implications emerge.

Firstly, the Trunfio and Campana's (2019) visitor experience model for mixed reality in museums can be applied, considering specific items such as interaction with museum servicescape and multimedia elements (interaction dimension); exhibition, service, historical period and city attraction (museum information dimension); audio and image and video (format dimension), multiple language capability (customisation dimension) and easy to use (usability dimension). A new museum business model may be tested (Trunfio & Campana, 2019) in which interactions between visitors, museum servicescape and multimedia technology combine authenticity with innovation.

Secondly, the importance and performance analysis evidences how functional elements reducing the sense of presence during the experience (Wang et al., 2018) receive low importance, calling scholars and practitioners to focus on the key service features to enhance visitor satisfaction and museum competitiveness.

Thirdly, this paper accepts the challenge to contribute with effective human-technology interaction in museums to explore how historical, artistic and cultural values can be combined with a new experiential visit. It creates the managerial condition for heritage preservation and virtual accessibility (Bekele et al., 2018; Guttentag, 2010).

Last, but not least, 'The Ara As It Was' project proposes an innovative service model in which revenue and new job opportunities create synergies and service value, enhancing the reputation of the museum and generating multi-target mobile applications.

Museum managers can learn from this account on the diverse factors of the mixed reality experience when defining new strategic scenarios and re-evaluating investments. Future challenges will be able to widen the analysis of MR in museums to other typologies of the museum—such as industrial and science museums etc.—in order to define possible technology-human-service interaction models.

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A Classification of Virtual Reality Technology: Suitability of Different VR Devices and Methods for Research in Tourism and Events

Shinyong (Shawn) Jung and Jiyong Jeong

Abstract The purpose of this study is to review previous literature on Virtual Reality in tourism and events and suggest suitable VR devices for diverse research purposes and methods of each study. This paper provides a classification of VR devices based on physical connectivity, tracking system, and user behaviour. Then, a systematic overview of recent VR research in tourism and event and recommendations of suitable VR devices for each study were provided. Twenty one academic articles were reviewed by two VR engineers and one tourism/event expert. The current analysis can be used as a guideline for researchers to identify the right VR technology to collect and measure more relevant data, which in turn will increase the validity of research in general. This paper offers managerial implications for industry practitioners as well.

Keywords Virtual reality · Tourism and events · Classification · Physical connectivity · Tracking system · User behaviour

1 Introduction

Virtual Reality (VR) technology has evolved into a level where users can have a fully immersive experience without feeling of nausea or any other uncomfortable feelings (Hudson et al., 2018). As both technology and applications are rapidly improving, a number of empirical studies have investigated individual perceptions or attitudes of various factors including immersion (Hudson et al., 2018), enjoyment (Rynarzewska, 2018), and social interaction (Beach & Wendt, 2016). However, limited research have focused on different types of VR devices (e.g., PC-tethered VR, standalone VR and Smartphone VR) by different implementation methods (e.g., seating, standing, mobility) and their applications on different products or segments of industry. For

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example, if a destination marketing organization's goal is to simply show travellers venues and attractions in a virtual setting, stationary VR or desktop scale VR with a seating method will be appropriate to be used, whereas a room scale VR or standalone VR with a mobility setting will be more effective for users to experience a fully immersive music festival walking around the festival venue, checking out different vendors virtually. Nevertheless, these assumptions have no strong evidence from technical perspectives.

As VR technologies provide applications to tourism and events industry in various aspects including marketing, entertainment, policy-planning, heritage tourism, site visit, and more (Huang et al., 2016), current academic VR research should address actual problems the industries are grappling with. The effectiveness of VR is essentially dependent on different applications, purposes, and needs of individual companies and organizations. Therefore, the purpose of this study is to review VR literature in tourism and events and suggest suitable VR devices for diverse research purposes and methods of each study. A classification of VR devices based on technological aspects such as physical connectivity, tracking system, and user behaviour from VR engineers' viewpoints supports the justification for the VR device recommendations. The current analysis is expected to provide a guideline for researchers to identify and choose right VR technology to collect data. This in turn will help not only increase validity of future VR research in general but also provide more practical implications for the tourism and events industry.

2 Classification of Virtual Reality Technology

VR devices can be classified into various categories depending on different viewpoints. In terms of physical connectivity, it can be divided into PC-tethered VR (e.g., HTC VIVE, Oculus Rift, MS MR), Console-tethered VR (e.g., SONY PS VR), Standalone VR (e.g., HTC VIVE Focus, Oculus Quest), and Smartphone VR (e.g., Google Daydream, Samsung Gear VR). In terms of user behaviour, VR devices can be divide into stationary VR, desktop scale VR, room scale VR, and mobility (non-space constraint) VR.

The criteria for classifying VR devices based on user behaviour are closely related to not only the physical connectivity but also the motion tracking method and performance of each VR devices (Vergara, Rubio, & Lorenzo, 2017). The motion tracking technology, one of the core technologies of VR devices, can be divided into head tracking and position tracking technology. The head tracking is a technique to obtain orientation values using the gyroscope, accelerometer, and magnetometers values of the Internal Measurement Unit (IMU) sensor in the headset. Since the head tracking can only get orientation values and cannot obtain translation values, many VR devices are applying additional position tracking technology. The position tracking technology can be divided into outside-in method which the headset or controller is tracked by an external device (e.g., HTC VIVE—Base-station, Oculus Rift—IR

Camera) and inside-out method which the camera is placed on the headset to determine how position of the headset is changing in relation to the external environment (e.g., MS MR, Standalone VR). The outside-in method has disadvantage of requiring a separate external device, but has advantage of better position tracking performance than inside-out method.

The stationary VR refers to a VR device that can be used only in a stationary state because it does not have the position tracking function. (e.g., smartphone VR). The desktop scale VR refers to VR devices that should be used around a PC or console because of their narrow position tracking coverage (e.g., some PC-tethered and console VR). The room scale VR refers to a VR device that can be used with little restriction on the distance to the PC due to the wide range of position tracking coverage (e.g., HTC VIVE & VIVE PRO). The mobility (non-space constraint) VR refers to VR devices that can be used without limitation in space because it is not physically connected to the PC or console but also has position tracking function (e.g., standalone VR). The PC-tethered VR device have both strengths and weaknesses compared to standalone (mobility) VR device. The PC-tethered VR device have position tracking accuracy of less than 1 cm by using powerful computational work of PC (Borrego et al., 2018), but there is a restriction in terms of mobility compared to the Standalone (Mobility) VR device since it has to be physically connected to the PC. The inside-out method, which requires good computer vision because it uses the 2D image data from the camera attached to the HMD, is at a disadvantage in tracking accuracy compared to the outside-in method, which is a method of optical tracking such as IR LED and IR laser. The classification of VR devices based on various viewpoints discussed above is summarized in Table 1 and Fig. 1.

3 Methodology

A literature search was conducted within academic research articles published between 2015 and 2019 excluding thesis and dissertations. Search was limited to the particular period because VR technology had become more accessible and affordable to users since 2015 when Google announced Cardboard, which the users can place their smartphone in the cardboard holder to experience VR contents. VR has been considered an alternative to actual travel or site visit by a number of professionals due to technological improvement (Tussyadiah et al., 2018). Database used in the search includes *Business Source Premier, Emerald Insight, and Google Scholar*. The search terms used were virtual reality, and tourism or event.

Two VR research engineers and one tourism/event expert reviewed 21 articles to provide their views on suitable VR devices for various investigations. The reviews were classified into three categories by mobility and tracking performance based on Fig. 1: stationary VR, desktop-scale VR, and room-scale VR/mobility VR.

Table 1 A classification of VR Devices based on different perspectives

Model	Physical connectivity	Tracking system			User behaviour	Recommended working area
		Head tracking	Position tracking	Position tracking methods		
HTC VIVE & VIVE Pro	PC-tethered	O	O	Outside-in	Room scale	Up to 5 m from the base station
Oculus Rift	PC-tethered	O	O	Outside-in	Desktop scale	Up to 2 m from the IR camera
Microsoft MR	PC-tethered	O	O	Inside-out	Desktop scale	Up to 4 m radius from the centre
SONY PSVR	Console-tethered	O	O	Outside-in	Desktop scale	Up to 2 m from the camera
HTC VIVE focus	Standalone	O	O	Inside-out	Mobility	No constraints
Oculus quest	Standalone	O	O	Inside-out	Mobility	No constraints
Google daydream	Smartphone	O	X	–	Stationary	Stationary
Samsung Gear VR	Smartphone	O	X	–	Stationary	Stationary

4 Review of VR Research in Tourism and Events and Suggestion

The proliferation of the VR technology has generated numerous research articles in Tourism and Events (Beck, Rainoldi, & Egger, 2019). While some articles disclose specific types of VR device used in the study, many other studies either do not disclose types of VR device or simply mention it VR in general. Tables 2, 3 and 4 provide overview of studies addressing effects of VR in tourism and events and lists of used VR device (if provided in the study) or suggested VR devices for the studies based on their methodology and variables investigated in each study.

For example, Debailleux et al. (2018) tested participants' experience of a virtual 3D-modeled cultural heritage using oculus rift which is classified as a desktop scale VR device. In this case, it is recommended to use a room scale VR or a mobility VR device such as Oculus Quest and HTC VIVE Focus that allows users to move freely to maximize the effect of virtual tour. Likewise, the study of Disztinger et al. (2017) investigated factors that determine the acceptance of VR technology in travel planning by surveying participants who experienced a variety of VR device types

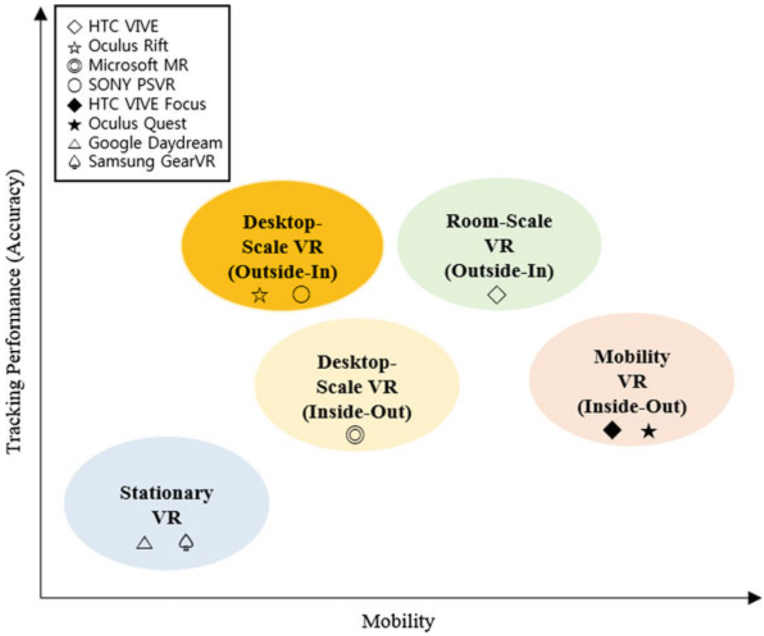

Fig. 1 A classification of VR devices by tracking performance and mobility

including Google card board, HTC Vive, and Oculus Rift. However, the study did not separate the samples by different types of VR devices such as stationary VR, Desktop-Scale VR, and Room-Scale VR. Categorizing each experiment based on different types of VR device can help the study draw the conclusion with more practical implications for specific purposes. The analysis presented in following tables can be used as a guideline for researchers conducting follow up and future studies that will examine VR experiences in tourism and events sector.

5 Implications

VR has created new tourism experiences for travellers in terms of entertainment, education, and heritage preservation becoming a source of information of destinations/tourism sites (Beck, Rainoldi, & Egger, 2019). Furthermore, VR significantly influences on increasing business as well as leisure travellers' intention to visit destinations (Tussyadiah et al., 2018). With the continuous technology advancement, various types of VR device play different roles in making the most of the tourism experiences and destination marketing effects depending on user's goals and objectives. In this regard, this review paper provides important theoretical and practical implications.

Table 2 Studies using or suggested to use stationary VR

Research by authors (years)	Measurement	Methodology/device used
Guerra, Pinto, and Beato (2015)	New value that can be provided to tourism and heritage through VR technology	Conceptual paper
Huang, Backman, Backman, and Chang (2016)	The influential factors that affect virtual tourist experiences and behavioural intentions within a virtual tourism destination	Online questionnaire
Wiltshier and Clarke (2017)	The antecedents to the successful use of virtual cultural tourism and the ways in which realities can add value to cultural tourism offers	Conceptual paper
Tussyadiah, Wang, and Jia (2017)	The spatial presence in VR environment and its attitudes toward tourism destination	Experiment and questionnaire/Google card board and Samsung Gear VR
Disztinger, Schlogl, and Groth (2017)	The influence factors that determine the acceptance of VR technology in travel planning	Experiment and questionnaire/Google Card board, HTC vive, and Oculus Rift
Tussyadiah, Wang, Jung, and tom Dieck (2018)	The effect of VR experience on the presence and attitude change in the tourism industry	Online questionnaire
Femenia-Serra, Perles-Ribes, and Ivars-Baidal (2018)	Impact of VR on expectations placed on the smart destination	Online questionnaire
Rynarzewska (2018)	The consumer expectation factors affecting the adoption of VR in sports industry	Online questionnaire
Wagler and Hanus (2018)	The impacts of VR tourism experience on attitude and enjoyment	Conceptual paper
Gibson and O'Rawe (2018)	The impact of VR experience on the likelihood to visit the featured region	Experiment and questionnaire/Samsung Gear VR
Wei, Qi, and Zhang (2019)	The power of VR technology in improving visitors' satisfaction with theme park	Experiment and online questionnaire

Table 3 Studies using or suggested to use *desktop-scale VR*

Research by authors (years)	Measurement	Methodology/device used
Martins, Goncalves, Branco, Barbosa, Melo, and Bessa (2017)	Propose a theoretical model that supports multisensory virtual tourism experience and applies it to wine tourism	Conceptual paper
Kim, Lee, and Jung (2019)	The factors that encourage potential tourists to visit the destinations presented in VR activities	Online questionnaire
tom Dieck, tom Dieck, Jung, and Moorhouse (2018)	The factors that affects the tourists' VR adoption and behavioural intentions in tourism	Experiment and questionnaire/Samsung Gear VR
Wagler and Hanus (2018)	Comparing virtual reality tourism to real-life experience: effects of presence and engagement on attitude and enjoyment	Experiment and questionnaire/Oculus Rift

Table 4 Studies using or suggested to use *room-scale/mobility VR*

Research by authors (years)	Measurement	Methodology/device used
Jung, Lee, tom Dieck, and Chung (2016)	The effect of VR on museum visitor experience enhancement and revisit attraction	Experiment and questionnaire/Samsung Gear VR
Marchiori, Niforatos, and Preto (2017)	The effects of the formation of strong memories of VR experience	Experiment and questionnaire/Oculus Rift
Jung and tom Dieck (2017)	The value for the museum visitor experience through VR and AR technology	Conceptual paper
Martins, Goncalves, Branco, Barbosa, Melo, and Bessa (2017)	The method for applying multisensory virtual experience to wine tourism industry	Conceptual paper
Debailleux, Hismans, and Duroisin (2018)	The learning outcome of the virtual tour through VR experience	Experiment and questionnaire/Oculus Rift
Kim and Hall (2019)	The hedonic factors of perceived enjoyment and flow state in the VR tourism context	Online questionnaire

First, by implementing the device recommendations provided in the completed study, scholars studying VR experiences in tourism and events will be able to ensure internal validity of their experimental design. This in turn will allow more accurate analysis of the causes and effects of the study. For instance, even if a study found a positive causal effect of VR on tourism experience, using an alternate VR device could generate different results. With continuous technological advancement, selecting a suitable VR device that meets research goals is crucial in future success of VR studies in tourism and events.

Second, the current review provides a novel classification of VR in tourism and events based on technical aspects such as physical connectivity, tracking methods and user behaviour. Therefore, tourism and events scholars who are not experts in VR technologies can benefit from this study when designing their research. Moreover, this paper will inspire researchers to take perspectives of VR engineers and technicians into account in an effort to develop a more accurate experiment and survey questionnaire.

Lastly, the industry will eventually find academic research that provide more practical implications useful, especially when it comes to adopting a specific type of VR device. Depending on the organizations' purpose, needs, and application intention, various research findings about the effectiveness of VR will not only help the organizations make a right decision on whether to adopt the VR technology, but also guide them to select a suitable VR device among many other options.

6 Conclusion and Limitations

This study reviewed research articles published between 2015 and 2019 that examined effectiveness of VR in tourism and events industry. By analysing methods and measurements of each study, this paper offers recommendations of suitable VR devices from engineers' perspective. Specifically, a classification of VR device based on physical connectivity and user behaviour provides researchers with insights into which VR device type (e.g., stationary, desk-top scale, room-scale, and mobility) would be appropriate for different research methodologies or variables measured in VR studies in tourism and events. The classification of VR devices further provides scholars and practitioners with suitability of VR devices by tracking system (e.g., head-tracking and position tracking) and position tracking method (e.g., outside-in and inside-out) for various research purposes and practical applications.

Although VR research in tourism have leapfrogged over the past few years in terms of both quantity and quality (Beck et al., 2019), a number of them have treated VR simply as an emerging technology, often overlooking important technical aspects such as physical connectivity and tracking methods of VR devices. As each VR device type is optimized for different user activities, both researchers and practitioners should be able to choose the proper device when putting their ideas into practice.

The advancement of VR technology creates more applications for tourism and events industry (Moro et al., 2019). At the same time, it requires researchers and practitioners an advanced knowledge of VR such as device types, specifications, and pros and cons, in order for them to make the right decision. While this paper took a critical step towards integrating engineers' perspectives in categorizing and suggesting VR devices for tourism/event research, contribution is limited in a couple of aspects. First, a more universal consensus is needed on the categorization of the VR devices among VR engineers and content developers across the globe. As the technology evolves rapidly, the current classification based on user behaviours can be viewed differently depending on performance of VR devices by different manufacturers such as Oculus, HTC, and Play Station. Second, recommendations provided in Tables 2, 3 and 4 are still subjective as they reflect perspectives of limited number of VR engineers and tourism/event expert. A more comprehensive review from VR experts who represent all types of VR device manufacturers, content developers, and tourism/event industry practitioners should be taken into consideration in the future study.

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AR and VR in Research

Meta-Analysis of Global Activities in Augmented Reality (AR) and Virtual Reality (VR)

Johan Pognon, Jacques Chi, Alexandre Salabert, Kangsoo Kim and Si Jung Kim

Abstract Motivated by Mark Billinghurst's work about where AR (Augmented Reality) research is taking place, we investigated where VR (Virtual Reality) and AR (Augmented Reality) research is happening around the world based on scholarly articles published in the IEEE VR (Institute of Electrical and Electronics Engineers Virtual Reality) and ISMAR (International Symposium on Mixed and Augmented Reality) proceedings. We analysed a total of 414 papers published in the last six years from 2012 to 2017 at the ISMAR and IEEE VR. The study shows that the USA leads both VR and AR research followed by Germany and France. The number of published VR papers seems increasing, on the other hand, the number of published AR papers seems slightly decreasing.

Keywords AR · VR · Augmented reality · Virtual reality · ISMAR · IEEE VR · Proceedings · Mark Billinghurst

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1 Introduction

Augmented Reality (AR) and Virtual Reality (VR) are penetrating more and more into our daily life (Kour, 2015, www.ijsrp.org). Parallel worlds are alive and plunge us into alternate realities. Motivated by Mark Billinghurst's work, "where AR research is taking place," (2018, May, https://medium.com/@marknb00) we have extended his work by investigating the global activities in AR and VR by analysing papers published in IEEE VR (Institute of Electrical and Electronics Engineers Virtual Reality, http://www.ieeevr.org) as well as IEEE ISMAR (International Symposium on Mixed and Augmented Reality, http://ismar.net). This study focuses on the global activities in AR and VR research and provides the trends and characteristics of the activities.

2 Methods

The method used in this study follows an analytical approach where we analysed the six years of proceedings published in the ISMAR from the year 2012 through 2017 as well as another six years of proceedings published in the IEEE VR from 2012 through 2017 totalling 414 papers. The reason for choosing the IEEE VR and ISMAR is that both societies are the flagship international academic conferences for the fields of AR, VR and Mixed Reality (MR).

3 Results

3.1 Global Activities Viewed from IEEE VR Papers

Table 1 provides the breakdown of the countries sorted by the number of papers published in IEEE VR. It shows the name of the countries as well as the ratio of the papers per institution calculated by Eq. 1. Figure 1 is the geographical representation of the data listed in Table 1. As seen from Table 1 and Fig. 1, almost the half of the VR papers published are from the U.S. Austria has the highest publication per university ratio of 4.67 over six years.

$$ratio = \frac{\#papers}{\#universities} \quad (1)$$

Although the U.S.A. has published the most amount of papers, the publication ratio per institution is only 2.28 that means institutions in the country have only published around two papers over the six years. Europe is the leading continent producing highest volume of VR papers while Africa is the only continent that does

Table 1 Top 10 countries published VR papers in IEEE VR during 2012–2017

Rank	Country	Number of papers	Number of universities	Ratio	Population	Ratio 2
1	USA	98	43	2.28	325,700,000	300.89
2	Germany	25	11	2.27	82,670,000	302.41
3	France	22	9	2.44	66,900,000	328.85
4	UK	15	9	1.67	65,640,000	228.52
5	Japan	15	7	2.14	127,000,000	118.11
6	Austria	14	3	4.67	8,823,054	1586.75
7	China	11	8	1.38	1,379,000,000	7.98
8	Spain	8	2	4	47,725,002	167.63
9	South Korea	5	4	1 25	51,250,000	97.56
10	Australia	3	2	1.5	24,130,000	124.33
10	Canada	3	1	3	36,290,000	82.67
10	Denmark	3	2	1.5	5,785,864	518.51

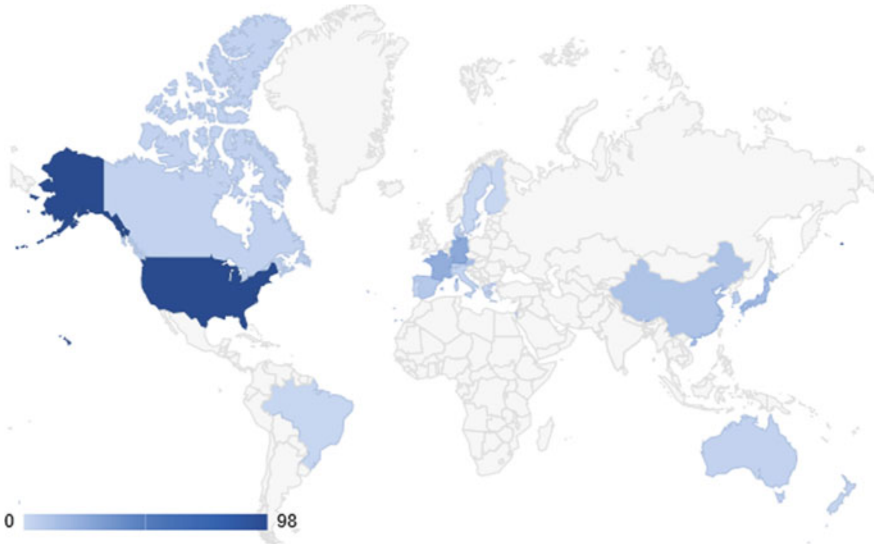

Fig. 1 Visualization of the countries published VR papers in IEEE VR during 2012–2017

not produce any papers in VR. Table 2 shows the rank of the country that lists countries produced most papers per population by the ratio 2 calculated by Eq. 2.

$$ratio\ 2 = \frac{\#papers}{population} \times 10^9 \tag{2}$$

Table 2 Top 10 of number of IEEE papers per country sort by the ratio 2

Rank	Country	Number of papers	Number of universities	Ratio	Population	Ratio 2
1	Austria	14	3	4.67	8,823,054	1586.75
2	Denmark	3	2	1.5	5,785,864	518.51
3	New Zealand	2	2	1	4,693,000	426.17
4	France	22	9	2.44	66,900,000	328.85
5	Germany	25	11	2.27	82,670,000	302.41
6	USA	98	43	2.28	325,700,000	300.89
7	Switzerland	2	2	1	8,372,000	238.89
8	UK	15	9	1.67	65,640,000	228.52
9	Finland	1	1	1	5,495,000	181.98
10	Spain	8	2	4	47,725,002	167.63

As seen in Table 2, Austria is the leading country that produces the most VR papers per institution. In Spain, 2 universities have published 8 papers on VR. This is also suggestive of active work being done in VR. There are no Asian or African countries represented in Table 2. This is likely due to lack of funding or ‘brain drain’ from these regions. We can conclude that European countries are quite focused on VR technology. While the US has a huge number of universities working on VR research, they do not publish much. There is room in the US for a much broader avenue of published research.

Figure 2 shows the number of VR papers per country from 2012 to 2017. It is easy to see that the USA publishes a lot of papers every year and dominates in this field. Germany and Japan tend to publish the same number of papers each year whereas France published a lot in 2014 and 2015.

It is interesting to compare numbers between continents. Figure 3 shows the evolution from 2012 to 2017 of the number of papers published. Of the seven continents, Africa is not represented because none of the regional institutions published anything about VR.

Overall, Asia increases their number of papers slowly but in a constant way. If we take a step back, we see Europe publishing more and more proceedings (for a long period). Concerning North America, it pretty much found its way back in 2017. Oceania and South America are not active in VR; they do not publish regularly.

The ten institutions with the largest number of published IEEE papers are shown below. It is interesting to note that the top ten is composed of the USA and Western Europe. It shows us that institutions in Asia are not really publishing in the field of VR, even if they might be engaged in research.

If we analyse Table 3, we can conclude that the USA has 5 institutions publishing actively in VR (48 papers). That is as much as the number of institutions publishing actively in the whole of Europe (51 papers).

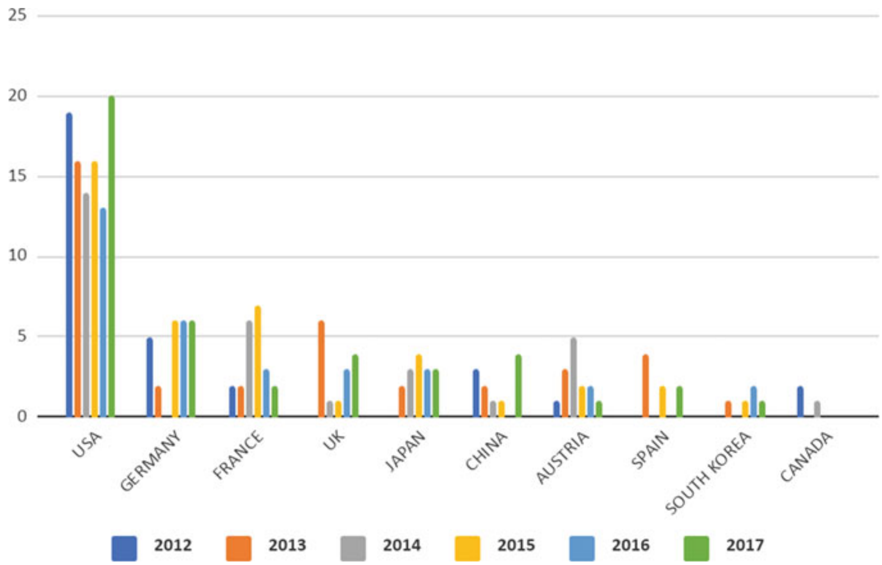

Fig. 2 The countries that published IEEE VR papers from 2012 to 2017

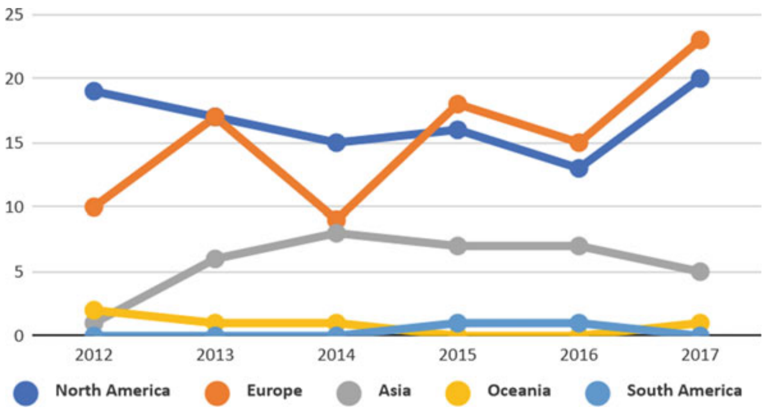

Fig. 3 Trends in the number of IEEE VR papers per continent for the last six years

To conclude, let us have a look on the number of IEEE VR proceedings over the past 6 years (Fig. 4).

Through the last six years, institutions publish more and more papers for IEEE VR. In fact, from 2014, the VR-related researches are increasing non-stop, this is linked to the continuous releases of VR headsets such as the Google Cardboard, Samsung Gear VR and the Oculus Rift (public). Thus, researchers tend to conduct a lot of user studies. From 2012 to 2017, the total of papers increased by about 39%.

Table 3 Institutions with the most IEEE publications

Rank	Institution	Country	#Papers
1	University of North Carolina—Chapel Hill	USA	18
2	INRIA	France	17
3	Graz University of Technology	Austria	11
4	University of Florida	USA	10
4	University of College London	UK	10
6	Virginia Tech	USA	8
7	University of Barcelona	Spain	7
8	Aachen University	Germany	6
3	Iowa State University	USA	6
8	University of Central Florida	USA	6

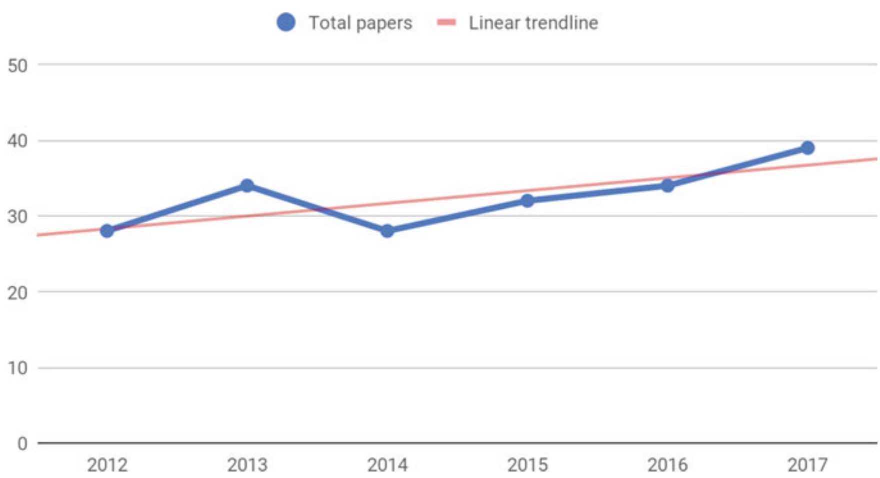

Fig. 4 Numbers of IEEE VR papers for the last 6 years

This is likely to continue since more and more major companies such as Microsoft are investing into VR (Mixed Reality Headset etc.).

3.2 *Global Activities Viewed from ISMAR Papers (Fig. 5)*

Table 4 shows the breakdown of leading AR researchers per country, the number of universities and the ratio (Eq. 1). As can be seen, over half of the top AR researchers in the world are in the USA and Germany.

The ten institutions with the largest number of published papers are shown below with Table 5, as well as the average number of publications per researcher at those

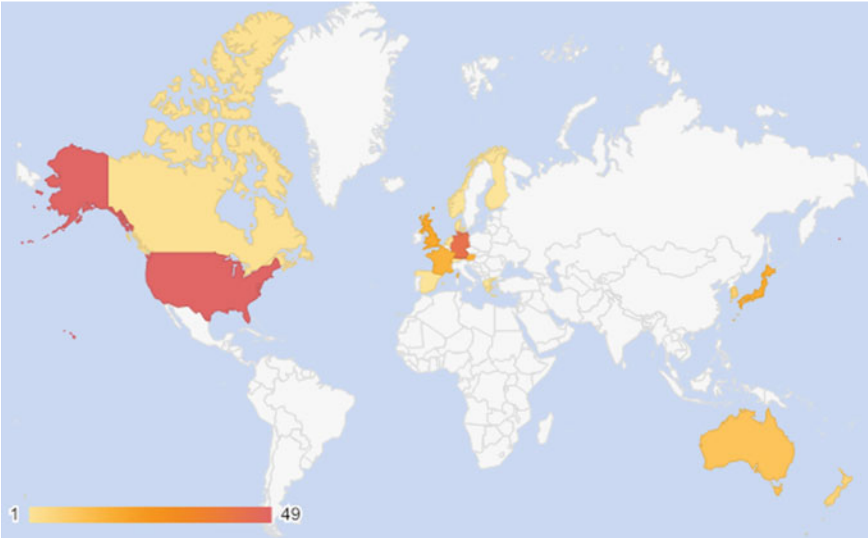

Fig. 5 Locations of the researcher who published papers at ISMAR 2012–2017 in the world

Table 4 Top 10 countries by the number of active AR researchers publishing papers in ISMAR 2012–2017

Rank	Country	#Papers	#Institutions	Ratio (Rank)
1	USA	49	30	1.63 (8)
2	Germany	43	15	2.87 (2)
3	UK	19	11	1.73 (7)
4	Japan	18	10	1.80 (5)
5	Austria	17	4	4.25 (1)
6	France	16	9	1.78 (6)
7	Australia	11	8	1.38 (9)
8	South Korea	7	3	2.33 (3)
9	New Zealand	6	3	2.00 (4)
10	China	5	4	1.25 (10)

institutions. It shows that while the US and Germany dominate in AR research, countries like Austria are publishing actively despite AR research being conducted at only 4 institutions.

However, if you look at the number of institutions that published ISMAR papers, you can see that the ranking is completely changed with Austria on top. Stronger ratios usually point to institutions who have invested in AR research, and see this area as important to the future of technology.

Table 5 Universities with the most AR publications by top AR researchers

Rank	Institute	Country	#Papers
1	Technical University of Munich	Germany	16
2	Graz University of Technology	Austria	12
3	Osaka University	Japan	8
4	UC	USA	6
5	UNC	USA	6
6	Microsoft Research	UK	5
7	DFKI	Germany	4
8	KAIST	South Korea	4
9	SRI International	USA	4
10	University of Canterbury	New Zealand	4

It is no surprise that the top institutions belong to the countries that have a high ratio in Table 5 especially Graz University which plays a large role in publishing papers for Austria (Fig. 6).

What it is interesting is that while the decreasing trend occurred everywhere, America and Europe are the only ones to go up again in 2017. Europe shows a steady rise from 2012 to 2014, with the slump in 2015. But by 2017, there is a significant rise in research compared to 2016. We can also notice that Asia has a big bump starting 2013, followed by two years of continual increase with a slump beginning in 2016. Oceania experiences only a slight rise in 2016.

Let us now turn to countries within the same continent, which can have different patterns in AR research.

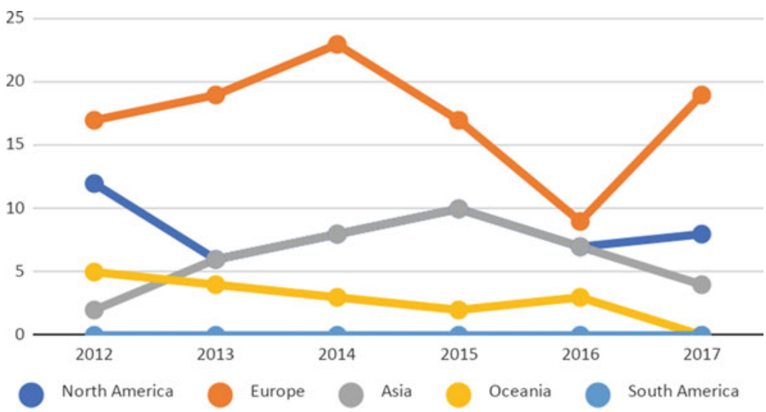

Fig. 6 Number of papers per continent from 2012 to 2017

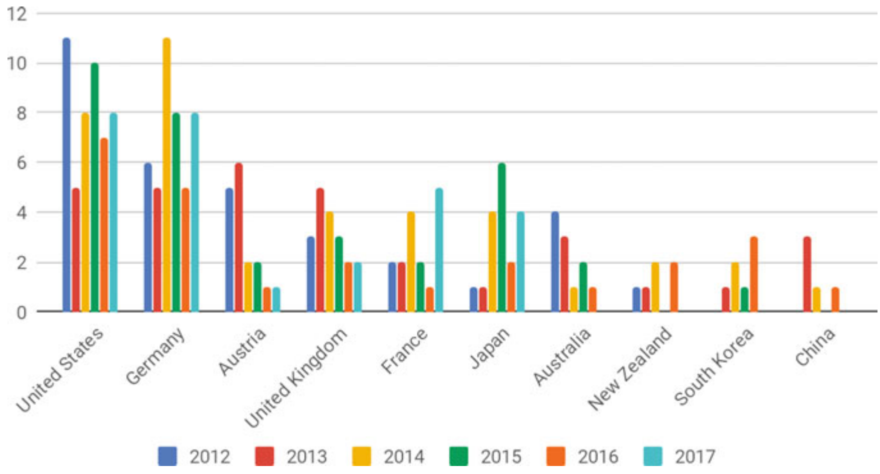

Fig. 7 Number of papers per country from 2012 to 2017

First, the big AR events that happened were the release of Google Glass and Nintendo 3DS, with AR features heavily publicized. After its release and gaining popularity, we can see a huge spike of interest in the countries. 2014 is generally a year of active AR research in most of the countries in Fig. 7. While New Zealand shows low research interest over 2012 and 2013, the boost in 2014 and is maintained in 2016. China, on the other hand, shows a decline in research since 2013.

France and South Korea show higher than normal research activity by 2017, suggesting more institutional investment in AR research. For France, it may be explained by the fact that ISMAR 2017 was held in Nantes, which might have stimulated the investment in AR in order to attract media attention. Germany also has many technology related conventions such as IFA or more directly AWE (Overton, 2017) which could explain why German institutions also invest a lot in AR.

Figure 8 shows that the AR research trend is declining each year since 2014 (down almost 50%). This is linked to the Google Glass privacy scandal. However, in 2017 the situation is reversed and may continue thanks to popular AR-compatible games such as Pokémon GO but the aftermath of battle between the privacy laws and the technological improvements remains to be seen.

3.3 Duality of ISMAR Proceedings and SCOPUS

One difference to note between SCOPUS and ISMAR proceedings is that ISMAR has a stricter criteria for selection of papers, so, it will be interesting to note which institutions publish quality papers at least according to ISMAR.

Mark Billinghurst has written a great article about AR papers based on SCOPUS, let us try to use its data (Table 6).

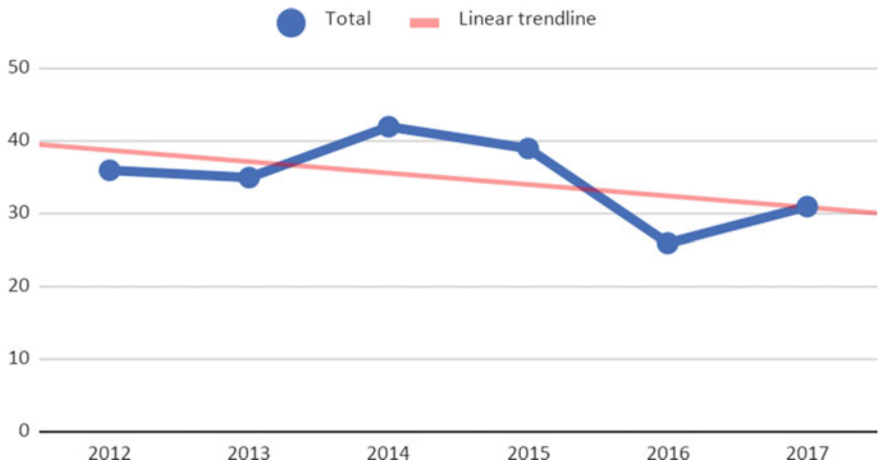

Fig. 8 Number of ISMAR papers per year

Table 6 Duality of the top ten institutions of #papers and #ISMAR proceedings (2012–2017) order by the ratio

Institute	Country	Total papers	#Papers ISMAR	Ratio (%)
Technical University of Graz	Austria	157	12	7.64
Technical University of Munich	Germany	276	16	5.8
KAIST	South Korea	104	4	3.85
MIT	USA	98	3	3.06
National University of Singapore	Singapore	152	4	2.63
University of Tokyo	Japan	123	2	1.63
Beijing Institute of Technology	China	252	2	0.79
Nara Institute of Science and Technology	Japan	377	2	0.53
University of South Australia	Australia	407	1	0.25
University of Evry Val d'Essonne	France	119	0	0

We are comparing them using the ratio given by the following Eq. (3):

$$ratio = \frac{\#papers\ from\ ISMAR}{\#papers\ from\ SCOPUS} \times 100 \tag{3}$$

Please note that the ISMAR study is very limited in scope since we are only focusing from 2012 to 2017 but it should be still interesting to analyse some results even if they are partial.

As mentioned earlier, the data we have from ISMAR is limited compared to SCOPUS, so, we cannot really conclude, but it still shows how strict the selection policy is for ISMAR publishing.

Some countries show a very low ratio. This can only mean two things, either the university published them too early/late which means it is out of our range of research, or it does not publish good enough papers according to ISMAR standards.

4 Discussion and Conclusion

We investigated where VR and AR research are happening around the world based on the IEEE VR and ISMAR proceedings. The U.S.A., Europe and Asia are active in this field. The best 10 institutions which are specialized in these areas of research are shown in Table 7. VR and AR follow two opposite paths. While the number of VR papers is increasing because it has reached its maturity in terms of technology allowing more applications study to flourish, the AR seems to be decreasing but popular AR-based game such as Pokémon Go, or Jurassic World may save it.

As expected, most top countries stay in the high-end of the ranking. The most balanced countries are situated in Europe which is calculated by the ratio (Eq. 4). It should be interesting to find the reason behind the disparity in the other ones.

$$ratio = \frac{\#papers\ from\ VR}{\#papers\ from\ ISMAR} \quad (4)$$

Some countries seemed to focus more on VR because their institutions may have more resources to spend on expensive VR equipment (state-funding, partnership, etc.) than the others. The popular HMD such as the final version of Oculus Rift has

Table 7 Top ten of countries sort by number of papers published (VR + ISMAR) from 2012 to 2017

Rank	Country	VR paper	ISMAR paper	VR + ISMAR	Ratio
1	USA	98	49	147	2.00
2	Germany	25	43	68	0.58
3	France	22	16	38	1.38
4	UK	15	19	34	0.79
5	Japan	15	18	33	0.83
6	Austria	14	17	31	0.82
7	China	11	5	16	2.20
8	Australia	3	11	14	0.27
9	South Korea	5	7	12	0.71
10	Spain	8	1	9	8.00

only been commercialized in late 2015 and since its announcement in E3 2012 (with beta version), new VR capabilities were getting way more attention than the more mature AR technology.

However, Mixed Reality which is based on AR technology is more likely to become an attraction thanks to the AR glasses development (Bohn, 2018, www.theverge.com). Its future applications will differ from VR and while VR is more for niche markets mainly because of the costs, AR targets real-life tasks, so it may increase AR based study because active people are more likely to spend their time on something that has more "practical uses". Of course, VR is improving too, more immersive headsets are coming soon (Hayden, 2018, www.roadtovr.com/) so its performance may also influence further research for growth and development.

The map shown in Fig. 9 representing the number of papers published for IEEE VR and ISMAR. The bigger the circle, the more the country publishes papers. What we learn with this map is in general, countries are more focused on VR than AR, but in Europe it is the contrary.

Comparing VR and AR is not fair as these two technologies have different types of application. However, resources in institutions is limited. So, it is sensible to think that some countries need to prioritize one of the two depending on its needs. It is however very interesting to see that public reactions, whether it is acceptance or backlash, influences the decisions of these institutions. Each technology has its own path for development and the fact they are maturing means that the base technology is becoming cheaper, thus allowing more people to study and improve on both VR and AR technologies.

As the limitation of the study, we only analysed papers based on the last six years of proceedings published in the IEEE VR and ISMAR. Papers was selected before being released during IEEE VR and ISMAR conference. It means our analysis may

Fig. 9 Number of papers (IEEE VR + ISMAR) around the world from 2012 to 2017

not reflect the real scale of quantities of papers published by countries. In this study, we showed countries which publish the most important and innovative research year by year.

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Dependability Analysis of High-Consequence Augmented Reality Systems

Ernest Edifor and Eleanor E. Cranmer

Abstract Research on Augmented Reality (AR) has gained traction due to its plethora of benefits and range of applications. In high-consequence environments where the failure of a system can have devastating effects on human life and/or the environment, dependability (that is reliability and availability) are of utmost importance. Therefore, AR systems that form part of or constitute a high-consequence system need to be evaluated for their dependability. Unfortunately, AR research lacks a significant focus on this. Fault Tree Analysis (FTA) is a proven probabilistic risk analysis technique mainly used in engineering to analyse how the individual component failures of a system contribute to a total system failure. This research explores the use of an FTA-based technique for the dependability analysis of high-consequence AR systems. The proposed solution is applied to a real-world case study in the medical field and the results are discussed.

Keywords Augmented reality · Fault tree analysis · Risk analysis · Monte Carlo simulation

1 Introduction

Augmented Reality (AR) is at the forefront of modern technology, emerging as a key player in the fourth industrial revolution. AR applications allow the superposition of digital immersive environments onto the physical realm. This capability is particularly useful when an operation would be otherwise risky, expensive or even impossible. Although AR systems can be used to avoid risks, relatively few research efforts have risk assessed these systems to determine their dependability. In this chapter, dependability refers to reliability ("the probability that the system will perform its intended function under specified design limits") and availability ("the probability that the system is successful at time *t*") (Avizienis & Laprie, 2004; Pham, 2006). Without dependability analysis, it is very difficult to know how a system can

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be upgraded to improve its configuration, reliability and availability. This study proposes a novel method for performing a full dependability analysis of AR systems in safety-critical environments.

The authors propose the use of a fault tree analysis based technique for modelling and logically analysing safety-critical AR systems. Once the logical analysis has been performed, Monte Carlo based simulation is applied to the resulting model and analysed probabilistically to produce various dependability measures. The proposed technique has been applied to a real-world case study and the results have been discussed.

The results of this study enable investigators and stakeholders to identify the critical aspects of AR systems easily and to explore how the components of the AR system contribute to the dependability of the whole system. By so doing, such investigators are able to establish necessary risk mitigating policies and determine how resources should be allocated to boost the reliability and availability of AR systems.

2 Literature Review

2.1 Augmented Reality

AR applications blend the virtual and physical environment to create immersive and interactive experiences (Graafland & Schijven, 2016). As such, AR has received much attention in academia for its ability to enrich the way information is both presented and accessed (Li, Yi, Chi, Wang, & Chan, 2018). Based on these benefits, the use of AR to improve information visualisation in high-risk situations has gained interest in a number of sectors. For example, AR has been employed in medical training to decrease risks, increase patient safety, reduce costs, and crucially minimise morbidity (Graafland & Schijven, 2016). Within construction, AR has been integrated to advance current safety practices, improving risk and hazard identification, workforce training, skills transfer and ergonomics (Li et al., 2018), safety training, and accident prevention (Guo, Li, & Li, 2013). Other examples include the use AR to improve air traffic controllers' access and visualisation of information to improve safety (Gürlük, Gluchshenko, Finke, Christoffels, & Tyburzy, 2018), and increase hazard detection without interfering with safety tasks (Schall et al., 2013).

AR demonstrates much promise as an effective tool to improve training, prevention and awareness in high-consequence situations. However, AR systems are not without risks (King, Klinedinst, Lewellen, & Wassermann, 2016). The complete implementation of an AR system that involves software, hardware, human interaction etc., can have many points of failure (Belhaoua, Kornmann, & Radoux, 2014; Chen, Ling, & Zhang, 2011; King et al., 2016). However, research to date has failed to identify limitations associated with the dependability of AR systems in high-risk situations and the potential dangers they can pose.

In recognition of this gap, Graafland and Schijven (2016) suggested that "in order to be of value, applications must be able to transfer information to the user…however, literature to date is lacking to support such evidence". Similarly, Li et al. (2018) recommended that further exploration of evaluation methods and integrated analysis at technical, experimental and organisational levels is necessary. Elia, Gnoni, and Lanzilotto (2016) employed the Analytical Hierarchy Process (AHP) to analyse AR systems to inform the design of efficient designing AR applications in process manufacturing. Despite the wide use of AR systems in various sectors, such as medicine and construction, extant literature does not explore the dependability of AR systems. In high-consequence systems, such as medical training, failures must be minimised as much as possible. With limited extant literature on the dependability (reliability and availability) of AR systems in high-risk environments, there is a need for research in this area.

2.2 Fault Tree Analysis

Fault Tree Analysis (FTA) (Vesely et al., 2002) is a probabilistic risk assessment technique, employing graphical symbols and Boolean logic to determine how a system failure can result from combinations of basic component failures. FTA uses the Boolean OR and AND gates in its analyses. The OR gate is used to model the relationship between an output event and its input events, such that the output event occurs when at least one of its input events have occurred. For example, in Fig. 1 (left), the output event, *Z*, is triggered when its input event *X* has occurred or when *Y* has occurred. The AND gate represents a relationship between an output event and its input events, such that, the output event occurs when all of its input events have occurred. For example, in Fig. 1 (right), the output event *Z* occurs when both of its input events, *X* and *Y* have occurred—the order of the occurrence is irrelevant.

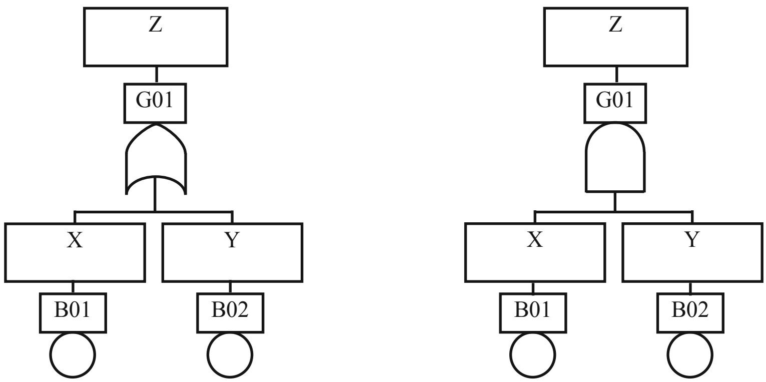

Fig. 1 FTA Boolean gates; OR (left), AND (right)

Broadly, FTA has two major phases: qualitative analysis and quantitative analysis. Qualitative analysis involves the evaluation of combinations of basic component failures, which by themselves, are sufficient and required to cause a system failure. These combinations are known as minimal cut sets. The quantitative analysis calculates the probabilities that the system failure (known as top-event) will occur and the contributions of basic components towards the top event happening. The quantitative analysis produces the evaluation of dependability values such as reliability, availability, mean-time-to-failure, sensitivity analysis etc.

Classical FTA is unable to capture, model and analyse the dynamic behaviours inherent in modern systems and therefore cannot analyse such dynamic behaviours to produce accurate quantitative results (Gulati & Dugan, 1997). The reader is referred to Walker (2009) for a detailed description of this limitation. Many extensions have been made to enable classical FTA to capture and analyse these dynamic behaviours more accurately. A critical review of some of these techniques is available in Walker and Papadopoulos (2009). In this study, only the Temporal Fault Tree (TFT) analysis technique (Walker, 2009) will be discussed because of its ability to model and analyse dynamic systems and comprehensive logical analysis capability.

2.3 Temporal Fault Tree (TFT) Analysis

To overcome some of the challenges of classical fault trees, TFT introduces three new dynamic gates: Simultaneous-AND (SAND), Priority-OR (POR) and Priority-AND (PAND). The SAND gate models the scenario where two events occur at exactly the same time. Since it is nearly impossible for two statistically independent events to occur at exactly the same time (Merle, Roussel, Lesage, & Bobbio, 2010), the SAND gate will not be discussed or considered in this study. The reader is referred to Edifor, Walker, and Gordon (2013) for extensions made to the SAND gate. The POR gate is used to model the situation where an output event occurs when its leftmost event occurs before subsequent events or only the leftmost event is required to trigger the output event. For example, in Fig. 2, the POR gate on the left will trigger the output event Z when the input event X occurs before Y (in case both have occurred) or where X occurs and Y has not (at a specific time). The PAND gate represents the situation where an output event is triggered only when its input events occur in a specific sequence—one after the other. For example, in Fig. 2, the PAND gate on the right is triggered only when the leftmost event X occurs strictly before the rightmost event Y.

Analytical techniques for evaluating the POR and PAND gates quantitatively have been discussed in Edifor, Walker, and Gordon (2012) and Fussell, Aber, and Rahl (1976) respectively. However, these techniques have limitations: (1) they are restricted to exponential distribution and/or non-repairable systems (2) they are unable to capture system environment data such as time of operation and repair. A simulation alternative has been proposed in Edifor (2014) to allow for the modelling and analysis of systems with different failure distributions but it is also unable

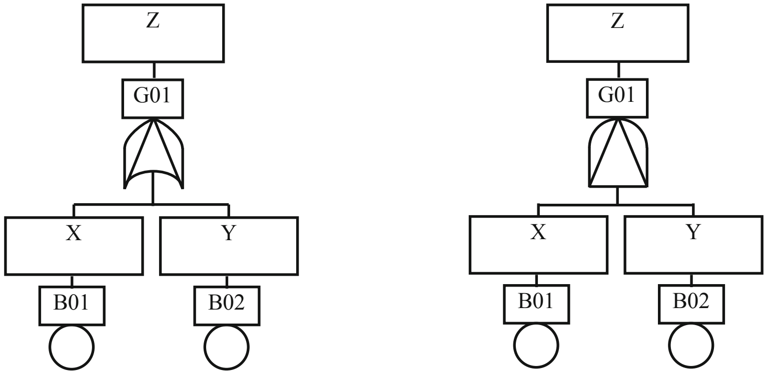

Fig. 2 TFT logic gates; POR (left) and PAND (right)

to capture different system operating data such as repair and preventive maintenance. The Goldsim software (Goldsim, 2018) is a Monte Carlo-based simulation platform that overcomes all the limitations stated above. However, Goldsim is unable to perform a comprehensive logical analysis of systems. TFTs is appropriate for capturing and analysing systems qualitatively but it is unable to perform full quantitative analysis. Goldsim is able to model and analyse systems quantitatively but it is unable to perform full qualitative analysis. The goal of this chapter is to use both tools—complementing each other—to perform full dependability analysis of high-consequence AR systems.

3 Methodology

Analytical techniques provide accurate evaluations of analysis while simulation techniques provide estimated values of systems. Most of the analytical techniques discussed above are restricted to component failures that have exponential failure distribution. Simulation (especially Monte Carlo simulation) is not restricted to any failure distribution and can have a high degree of accuracy when the simulation is run for a large number of iterations. Monte Carlo simulation is a mathematical technique that allows for modelling complex systems. Using random numbers, various variables in the system are simulated repeatedly to determine the behaviour of the system.

The Goldsim software uses Monte Carlo simulation in capturing, modelling and analysing the dynamic behaviours (such as sequential dependencies) that modern system exhibit. It is also able to capture and analyse special attributes of complex systems such as time of operation, flow rate etc. It can model and evaluate failure, repair, maintenance and replacement data with different failure distributions. Goldsim is able to evaluate systems to produce dependability data (such as reliability, availability, mean-time-to-repair etc.). However, it is unable to perform any logical/qualitative analysis. This study seeks to harness the benefits of both the TFT analysis technique and the capabilities of Goldsim. A three-stage technique is proposed for the full dependability analysis of high-consequence AR systems; these are modelling, qualitative analysis using TFT and quantitative analysis using Goldsim.

3.1 Modelling

AR systems could be as trivial as a home-based AR system that involves a phone and AR-enabled glasses. On the other hand, AR systems in safety-critical environments can involve many sub-systems. For example, in maxillofacial surgery (Zhu et al., 2017), a complete AR system will involve 3D Computed Tomography (CT) scanning, several computers, human involvements, software, markers, AR device, power supply, internet and etc. A framework is required for the identification and classification of risks and failure events in AR systems. Such a framework, which is currently non-existent, should standardise and facilitate the modelling of AR systems into temporal fault trees and it must serve as a protocol for accurately translating and mapping all aspects of the system into a temporal fault tree. The traditional FTA and TFT analysis notations make no provision for peculiar system attributes such as time of operation. The inclusion of such attributes contributes significantly to the accuracy of quantitative analysis. The authors propose the development of an annotated TFT that records peculiar system attributes to be used in quantitative analysis.

3.2 Qualitative Analysis Using TFT

Upon successful modelling of an AR system, the temporal truth table and temporal logic (akin to the Boolean truth table and Boolean logic respectively) can be used to reduce the AR system into its simplest and efficient configuration. This process is known as logical or qualitative analysis. Performing qualitative analysis of temporal fault trees can be done using one of two techniques—Archimedes or Euripides (Walker, 2009). The former is an inductive process for analysing temporal fault trees by translating the trees into a structure that enumerates all possibilities of achieving the most efficient configuration of the system. The latter is a deductive process for analysing fault trees by using an alternative step-by-step process to reduce the tree into its most efficient form.

The result of qualitative or logical analysis produces minimal cut sequences, which is synonymous to minimal cut sets. From the minimal cut sequences, single points of failure that are critical to the entire system failure can be easily identified. They also demonstrate how basic components should be interrelated to produce an efficient system.

3.3 *Quantitative Analysis Using Goldsim*

The qualitative analysis phase produces minimal cut sequences, which are necessary for quantitative analysis to take place. Using Monte Carlo simulation and the Goldsim software, a system can be modelled, simulated and analysed probabilistically to determine the probability that the system or its components will fail within a specific period. The contributions of each of these components to the overall system failure can also be evaluated. Useful metrics such as mean-time-to-failure, availability, mean-time-to-repair can also be determined.

In this section, a fault tree-based technique is proposed because it is a proven risk assessment technique that has stood the test of time. Temporal fault trees have the ability to capture dynamic behaviours in systems and provides comprehensive laws for analysing systems logically. Monte Carlo simulations are flexible and can adapt to almost any system featuring different failure distributions. The Goldsim software has complex mathematical formulae and algorithms for capturing all system data (failure, repair, maintenance etc.), performing dependability and causal analysis and displaying the results in intuitive ways that are easy to comprehend.

3.4 *Demonstration*

To demonstrate the proposed technique, the authors present the dependability analysis of a real-world high-consequence AR case study in the medical field. This case study is adapted from an AR system used for displaying nerve bundles in maxillofacial surgery (Zhu et al., 2017) as shown in Fig. 3. From the workflow in Fig. 3, virtual images are constructed from CT data using a 3D software. AR software tracks the

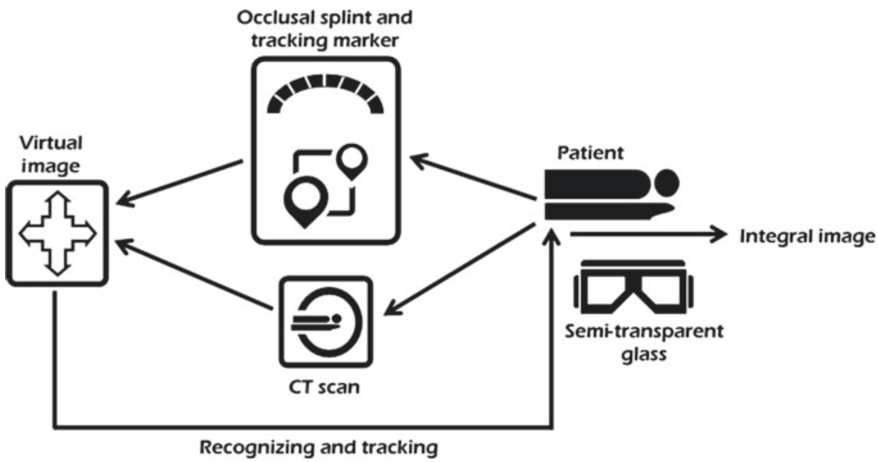

Fig. 3 Medical AR system case study

real environment. Fiducial markers are used to map the relationship between virtual images and real objects. A mixer superimposes the virtual image and tracking data unto the user's real-world view. In this scenario, the AR system includes the headset, CT projection, mixing device, tracking device, connection media, electric power etc. Peripheral sub-systems such as the power supply or connection media have not been included in the diagram. The power supply is a simple redundant system with a primary source of power and a secondary source of power.

To analyse the system above, it is assumed that the top-event (that is, system failure) is no or erroneous integral image produced. For the sake of demonstration, it is assumed that the combinations of component faults that can lead to the top-event are: failure in the tracking sub-system, mixer, power supply, headset or connection media. Table 1 is a summary of the assumed system environment data to be used for simulation. Exp., Wei., and Log. mean Exponential, Weibull and Lognormal distributions respectively. Stdev is the standard deviation. In the first row, the failure of the connection media (e.g. Bluetooth or Internet) has an exponential distribution failure hazard rate of 2.738E−4/day and a mean of 2 days for repairs. From the fifth row, the AR headset undergoes preventive maintenance every quarter with a mean delay of 1 day for repairs. In the last row, the controller that detects a failure in the primary power source and activates the secondary power source has a Weibull failure distribution with a scale and slope parameters of 1000 days and 2. It also has a lognormal repair distribution a mean and standard deviation of 2 days and 1 day respectively.

Table 1 Medical AR system data

Component	Category	Failure data	Repair data
Connection media	Connection failure	Exp. hazard rate: 2.738E−4/day	Exp. mean delay until repair: 2 days
Tracker	Setup failure	Wei. scale: 280 day; slope: 1.5	Log. Mean: 1 h, stdev: 10 min
Mixer	Software failure	Exp. hazard rate: 0.03/day	Exp. mean delay until repair: 1 day
Headset	Power failure	Exp. hazard rate: 6.845E−4/day	Log. mean: 2 days, stdev: 5 h
Headset	Preventive maintenance every 3 months	–	Exp. mean delay until repair: 1 day
Power	Power sub-system	Exp. hazard rate: 6.845E−4/day	Exp. mean delay until repair: 12 h
Power	Primary power internal failure	Exp. hazard rate: 6.845E−4/day	Log. mean: 2 days, stdev: 12 h
Power	secondary power internal failure	Exp. hazard rate: 9.126E−4/day	Log. mean: 1 day, stdev: 12 h
Power	Controller failure	Wei. scale: 1000 day; slope: 2	Log. mean: 2 days, stdev: 1 day

Table 2 Component result data

Component	Failure probability	Reliability	% Contribution to system failure
Mixer	0.882	0.118	67.37
Power	0.966	0.034	28.58
Tracker	0.037	0.963	1.96
Headset	0.02	0.98	1.53
Connection media	0.008	0.992	0.56

The above system and data were modelled and simulated in the Goldsim software with a system lifetime of 100 days, time-step of 1 day and 1000 iterations per day. The results show that the probability of failure, reliability and availability of the AR system are 0.967, 0.033 and 0.293 respectively. For a high-consequence medical system, these values are unacceptable. To identify how the system can be improved, it is important to know the failure probabilities of the various components and how they contribute to the total system failure.

Table 2 contains the probabilities of failure, reliability and percentage contribution of components to the AR system failure. It is evident that the mixer is the biggest contributor to the system failure although it is not the least reliable component; the least reliable component is the power sub-system. One reason why the mixer is the biggest contributor to the system failure but the power sub-system is the least reliable component could be because the power sub-system has redundant sub-systems—primary and secondary sources of power—but the mixer is a single point of failure. The connection media is the most reliable component and the least contributor to the AR system failure because even though it is a single point of failure, it has the highest level of reliability. With such information, investigators and designers are able to improve the system with the aim of enhancing system reliability. For example, using a more reliable mixer with a lower software failure rate will boost the performance of the mixer and the system as a whole.

4 Conclusion

Augmented Reality (AR) has proven to be a useful technology in hospitality, surgery, military etc. It provides the means of safely undertaking an operation that would otherwise be dangerous to the environment and human life or expensive. Although, AR can be used to reduce (and in some cases eliminate) risky operations, very little has been done in the dependability analysis AR systems. Developing a framework for assessing the dependability of AR systems will provide useful information on the reliability, availability, time-to-failure etc. of such systems. For safety-critical systems, such information is of utmost importance.

This study proposes a methodology for evaluating the dependability of AR systems. The authors suggest a framework be constructed for capturing and classifying risk drivers associated with AR systems. An improvement of the fault tree analysis technique, called temporal fault tree analysis can be used in modelling the AR system and analysed to produce the most efficient configuration of the system—this is called qualitative analysis. Goldsim, a Monte Carlo simulation-based software, can then be used to quantitatively analyse the system to determine how reliable and available the system is. It will also provide information on how component failures contribute to a system failure.

The proposed technique has been applied to a real-world case study. Using assumed system operating data, the case study has been modelled and analysed—the results have been discussed. The proposed methodology is capable of analysing systems with different failure distributions, has different system environment data (such as failure, repair and maintenance) and system configurations. A key area for improvement is the identification and classification of AR system risk drivers in high-consequence environments.

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AR and VR App Design and Content Creation

A Case Introduction of 'New Content Center' Incubating System for New Media Contents Startups Managed by Korea Creative Content Agency

Junchul Lim

Abstract Many countries, cities, and individuals all over the world are paying attention to the changes of technological development in the era of the Fourth Industrial Revolution, and are putting a lot of efforts into the daily life. In the era of the Fourth Industrial Revolution, the development of media technology is simply beyond the matter of how we can adapt to it. As the era of last industrial revolutions have always been, we must look for a positive change in our daily life and culture with a new frame. The Korean government is also making efforts to mature companies and foster ecological environment at the national level in the change of technological development. Such an effort should go beyond simply state administration, but at least we are receiving a clear message about what issues we should listen to now.

Keywords New content startups · 4th industrial revolution · AR/VR/MR · Korean government support · German Fairy Tale · Cultural convergence model

1 New Content Center

Korean ministries and affiliated communities are making various efforts to adapt new technologies into their field. The technological power of the Fourth Industrial Revolution calls for changes throughout our daily lives and it means that there is no field outside its influence in all of our lives. As part of these efforts, the culture and tourism sectors are moving toward fostering the development and activation of new contents and media such as AR and VR, and industrial ecosystems for this purpose.

Korean Ministry of Culture, Sports & Tourism have great concern to boost the AR/VR industries for preparing the 4th industrial revolution also and they made a incubating system, 'New Content Center' (as following NCC) managed by Korea Creative Content Agency to make new contents industrial ecosystem for fostering 'VR Hidden Champion' (actually 'VR' means all kinds of new contents in this sentence). They have two directions of policy, one is how to make corporation inter public and private field joint project promotion, and the other is to support for new daily life cycle in field of R&D, production, demonstration, experience, distribution.

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As shown in Fig. 1, NCC aims to establish industrial basement for promoting production and distribution through collaboration between creators, by lowering barriers to new contents creation by creating infrastructure for VR, AR, MR, and AI specialized in new contents industry. NCC have two years preparing time before taking into practice, and then have started to gather the companies concerning with new media contents making and distributing (1st step: 2018.01.01–2019.06.31). NCC have made budget (2.4 million $(US) (2017–2018)) to make financial support and incubation space (1114 m^2) for new contents startups being able to move into.

A number of 20 companies moved into the NCC for the first year. According to the size of the business, NCC selected five teams of 1 man company, eight teams of three persons companies, seven teams of five or more, and funded initial money for business according to the size of the company—it shows in Fig. 2—Tenant companies of NCC are preparing for content planning and production that could collaborate with various genres such as music, film, medical, education, employment, and so on. They also receive various kinds of professional consulting services such as finance, law, taxation and marketing through NCC's support programs.

Fig. 1 Direction of Korean government policy (2016–)

Fig. 2 Business scale and field of tenant company of NCC

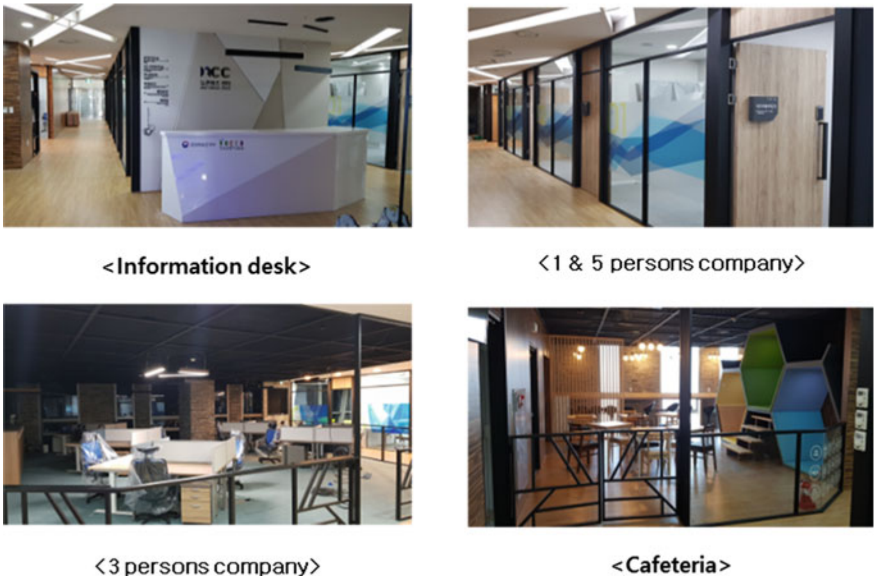

Fig. 3 Interior image of NCC

NCC have three major supporting programs. ① It supports incubation space for new contents startups and creators providing various infrastructure such as new contents startups incubation space(office)—Fig. 3 shows the interior image of NCC in office area—VR test bed, supporting initial development of funding, consulting for initial management of company, etc. And also, ② it does for new contents marketing and distribution (consulting and distribution support) supporting for new contents globalization marketing (funding), customized export consulting, etc. ③ NCC programs aim to establish infrastructure for new contents ecosystem, operation of various kinds of programs such as actual research on promising new contents field, such as new contents contest, hacker tones, activation forum, actual research, experience management, promotion, etc.

The most needed support for startups with ideas and skills can be summarized in three broad categories: funding, networking, and marketing. They can also work together and create synergies in an open space where they can share what they need, rather than doing it individually outside. In this sense, NCC is positive in terms of reducing the financial burden on companies and supporting networking and marketing what they actually need. NCC has been experiencing various trials and mistakes in operating the various support programs prepared from the stage of selecting the tenants. Of course, the governmental support cannot reflect 100% of the market demands. It seems that there is a still limitation responding to the various demands of the new contents companies which does not have an industrial ecosystem yet. However, considering the private sector is not able to secure its marketability, the efforts of the government to share the potentials and vision of new contents and to provide the support what they need are worthy of value. And we expect that these efforts will lead to more sustainable forms in the future.

2 Sample Case of NCC Incubating: Märchen Korea

Märchen Korea (as following, MK) is 1 man company and it was established during incubating period (July 20, 2018). MK have a project, [Märchen 360], cooperating with Märchenstrasse (German Fairy Tale Route) participating cities to build global platform using AR/VR technology. MK have made a contract with Hameln Marketing & Tourism GmbH to set AR/VR system in their tourist zone using German Fairy tale, 'Pied Piper' and Korean ICT technology. MK interpret the meaning of Märchen as traditional stories of each city's own have. Starting with [Hameln 360], [Märchen 360] will be developed as Global Platform enlarging the service area throughout the more participating cities of Märchenstrasse and Korean local area.

2.1 *Background of Business*

Currently, the trend of global culture and tourism has been changed as a market for user-oriented services, O2O technology that connects on and offline media, and inter-cultures convergence that goes beyond the virtual and real world. Service users who accustomed to digital media can enjoy their daily life according to their cultural favors and demands as shown in Fig. 4. Actually, Korea is no longer a special technology as like that because of rapid and advanced media technology development and proceeding, but its marketability is unstable also. Germany, on the other

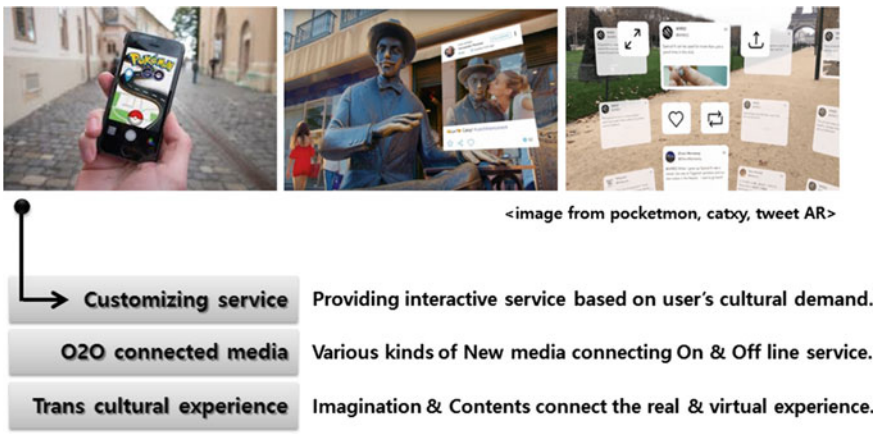

Fig. 4 Global trend of culture and tourism market

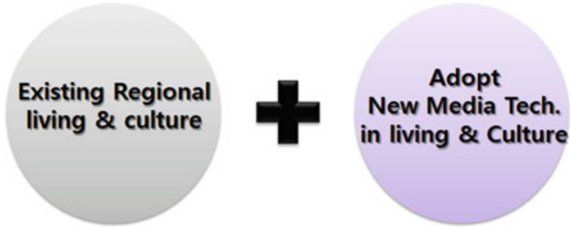

Fig. 5 First approach point of business

hand, has a lack of technical reflection on this field despite the fact that there is a real market demand. The effort to combine the advanced digital media technology of Korea with the stable culture and tourism market in Germany will bring an important opportunity to secure the marketability and diversity both sides of them.

Business of Märchen Korea focuses on two main points. The first point is how to adopt new media technology into our daily life. Every time that new technology has come to us, we have tried to look at the technology in the perspective of how we can follow it. But the meaning of developed technology can be found when our daily life could be enriched through it. So, we should find out the meaning of new technology while improving our daily life and focus on how we do for it. It means we should focus on the point how to adopt the new technology for improving our daily life, not just adjust and follow it. Figure 5 shows the business approach point of Märchen Korea.

The second point is to explore the possibility through inter-cultures convergence with new media technology. In fact, Korea and Germany have very different backgrounds in daily life and culture. However, if we look closely at the strong and weak points of each market, we can see that both of them can share developmental directions through cultural exchange and convergence. Figure 6 shows the possibility and expected benefits through convergence between two countries. Korea has the advanced ICT technology with global recognition, but relatively limited in the expansion of the market, and Germany has cultural assets and brand well-known to global market and stable domestic market but has a culture of slow and steady to adjust the changes of global trend. It is expected that they will have a clear win-win point for developing mutually positive direction with the effort of making digital

Fig. 6 Second approach point of business

communication channel in the field of culture and tourism sector that has not been frequent in the meantime before.

2.2 Märchenstrasse and [Märchen 360]

Märchenstrasse is a theme road which was proclaimed in 1975 on the theme of Brothers Grimm' life and stories, each stories of German Märchen, and the perspective of participating cities' marketing sharing the theme of it. Currently, Germany have more than 150 theme roads indeed, and Märchenstrasse has the fifth place popularity in the list. Many German cities have made efforts to be reborn as cultural cities after most of their industrial asset had destroyed since 1945, and as a part of this effort, many cities have created touristic products, theme road, that jointly run. The cities participating in Märchenstrasse also have made community together to activate and share the theme of Märchen in accordance with the characteristics of individual cities' own have. However, their efforts have been focused on offline promotions so far, and they are limited in providing interactive and consumer-oriented services in accordance with global trend changes of culture and tourism.

Focusing on this point, [Märchen 360] aims at delivering the diverse cultural assets of Märchenstrasse participating cities' own having before through new media services. Märchenstrasse having global popularity, is struggling with attracting new customers, not that it is a matter of cultural assets, but that there is a problem with how to communicate with service users who are accustomed to digital era. Sometimes, many German cities are hesitating to adopt new media technology and system due to lack of experience in using new technologies and difficulties in social consensus.

As shown in Fig. 7, [Märchen 360] offers a new way to enjoy Märchenstrasse with more fun. Märchenstrasse have various stories and characters already and each participating cities provide various kinds of sightseeing by creating many touristic

Fig. 7 Roadmap of [Märchen 360] project

products that match their regional characteristics. However, the services they have made are beyond the scope of traditional tourism services. [Märchen 360] will provide new media service that combines new media technology with existing cultural resources of Märchenstrasse and suggest ways for tourists to enjoy updated version of it in accordance with their individual cultural needs.

2.3 [Hameln 360] AR

Hameln is a major tourist destination in Germany with more than 3 million tourists annually. Various performances, events, and promotions related to 'Pied Piper' are being conducted throughout the year. Even though Hameln is a small town with 60,000 population, but they have made an effort to be a leading tourist city in Germany together with Hameln city, related community and company, and regional company concerning tourism. However, traditional offline promotions and campaigns have been hampered by the difficulty of attracting young and family-friendly tourists who are accustomed to new media, and overall services and visitors are getting old.

This is not a problem that Hameln only have. Germany has culture and tourism market with 274 mio (euro) scale, but domestic market share exceeds 80%. It means they have strong and stable market, but it has limitation in terms of market expansion also. In this sense, Hameln should catch up two points at once, attracting new customers while maintaining existing customers. In order to solve these problems, Hameln should make an effort to look at their market with flexible attitude. In other words, it is necessary to find a way to diversify existing cultural assets according to the demand of revisiting consumers, while providing new service taking the cultural demand of new visitors away from the conventional way of conveying information just in one-way. In order to open a new market, diverse efforts should be made to attract foreign visitors also. It means that it is urgent to open a new communication channel having added up attraction to satisfy demand of both sides of them. And Fig. 8 shows the characteristic points of [Hameln 360] AR.

Actually Hameln city have web-page, and they provide information on web. But it should be changed mobile oriented service. Web service is also digital technology, but it is no longer up to date. Mobile means that the service is provided in the center of users. Service users can get some information what they want immediately at every moment. They don't want to waste time while searching wide information on web. In this sense, the primary goal of [Hameln 360] is to create a communication channel that can organically communicate with various consumers using new media and system based on the existing cultural assets of Hameln.

As you could see it on Fig. 9, section classifying of [Hameln 360] could be divided two categories according to its characteristics. and also it could be explained with two words, 'interaction and attraction'. To catch up two points, we made a system using LBS and Game. In <Hameln AR, Game & Spot>, Service users will be able to get some information exactly where they are through location-based services and easily get the information what they need on their smartphone something about what are

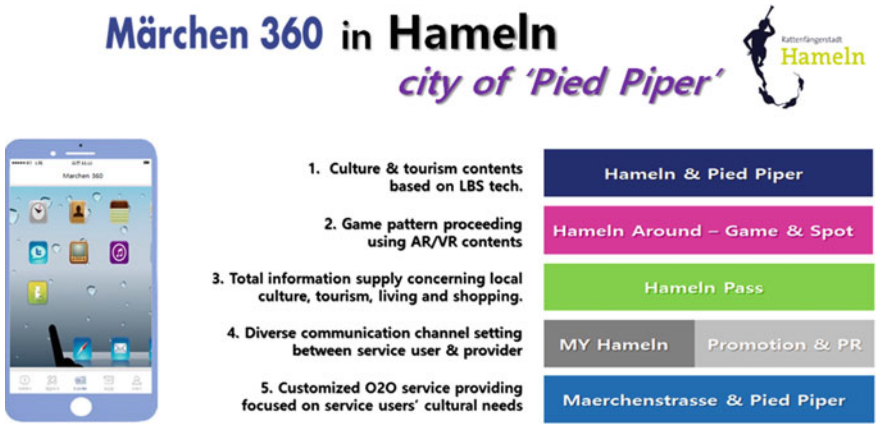

Fig. 8 Characteristic point of [Hameln 360] AR

Fig. 9 Business goal of [Hameln 360] AR

the name of buildings, what does signs mean, and every moments what they want to know immediately. Beyond providing travel information on mobile devices, they can enjoy the game through the new content service that utilizes the story and character of "Pied Piper" (Fig. 10). Actually, the composure of system based on the storytelling of "Pied Piper". Service users can get some rewards after doing something for Hameln, 'Catch the Rats' as like similar promise from the story. Of course it is a game, but it will help to provide a motif to be able to visit Hameln with more fantasy and fun.

One of the main objectives of [Hameln 360] is to find a practical way to help existing local-based service provider. Many service providers in local area are joining the global shared economic service model and provide their service, reservation and promotion. However, until now, global shared economic models are not based

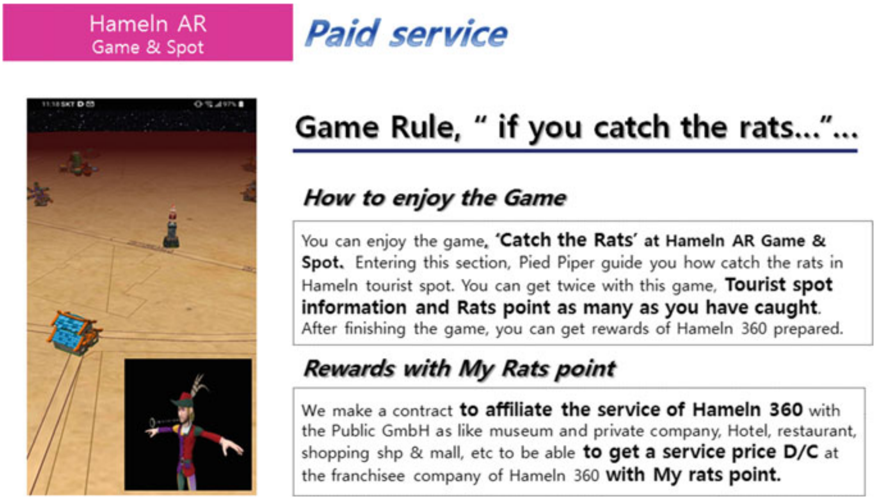

Fig. 10 Section classifying I: Hameln AR Game & Spot

on specific regions and cultures, and they have limitations in providing their own differentiated services.

In this section, [Hameln Pass], we try to match up the on and offline store and try to introduce service and product that local company of Hameln have. For the perspective of service user, they can enjoy the system exchanging the ‘Rat Point’ that they got through the game into service price D/C or souvenir that the franchise system prepared. Figure 11 shows you the service flow of [Hameln Pass]. Of course it takes more time to be a local economic friendly service, and it will need more franchisee partner in Hameln. But if this system could show them benefit while increasing their sale, there is no reason not to participate it even though they should pay some money for participating this project. Anyway, it can be a good advertising tool to connect service users and provider to match up their own needs.

[Hameln 360] is paid service basically and it aims at securing 300,000 users in the third year of business. It does not mean that all service users should be paid customers. [Hameln 360] have main business model while making cultural exchange contents. So, it will be developed as a direction of giving fair value to all of service users and service provider. Starting with [Hameln 360], it will be expanded the service area to other regions of Märchenstrasse as like Kassel, Bremen, Marburg, Hanau. And we hope that it will be able to create Global Märchen Platform by expanding cooperation with Asian cities that are interested in German and Korean inter-cultures convergence model, [Märchen 360].

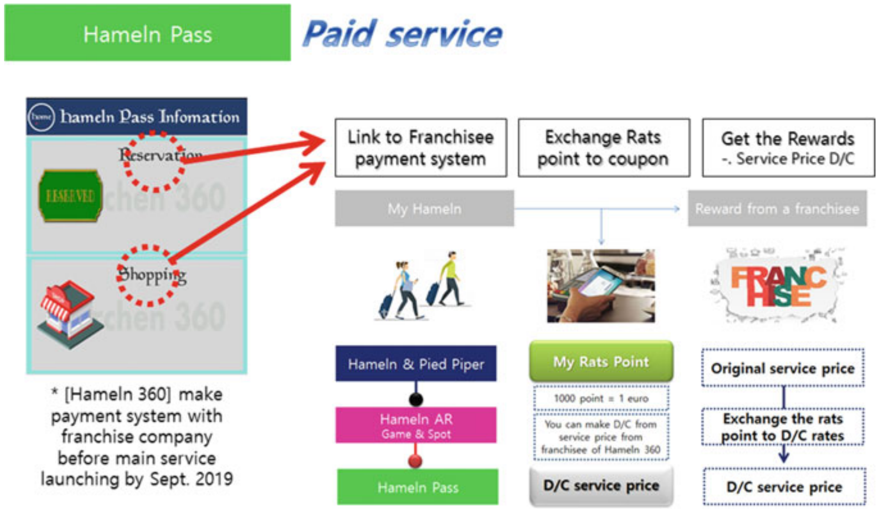

Fig. 11 Section classifying II: Hameln Pass

2.4 *Vision: Overseas Cultural Exchange and Global Märchen Platform*

[Märchen 360] is a project to explore the possibilities inter-cultures convergence model that promotes cultural exchanges between countries and regions sharing theme of Märchen (local based story) in the field of business. And [Hameln 360] will be a first trial of experimenting the possibility of converging the media assets of Korea with the cultural asset of Germany, 'Pied Piper'. Starting with [Hameln 360], we have talked with Märchenstrasse e.V (Association of German Fairy Tale Route) and Kassel Marketing for expanding the service area, and have a plan to invite Korean regional government, too. In addition, we will expand the service of [Märchen 360] to global market and cities that are interested in Korean and German culture as the name of Global Märchen Platform as it showed in Fig. 12.

Right now, the digital technology around us emphasizes the meaning of open mind with self-confidence, transparency between relatives, and expansion of networking. We have learned how difficulty it is to make any relationship between countries, regions, even in individuals. And new technology always come to us as a result of this trial and mistakes that we made. We should remind the meaning of new technology at every moment and try to concentrate on developing the relationship between people and cultural exchange using the experience and technology. In this context, we hope [Märchen 360] could make success stories contributing to vitalize global cultural exchange and bring some opportunity to overcome weakness each part own have while doing something fun and exciting with it.

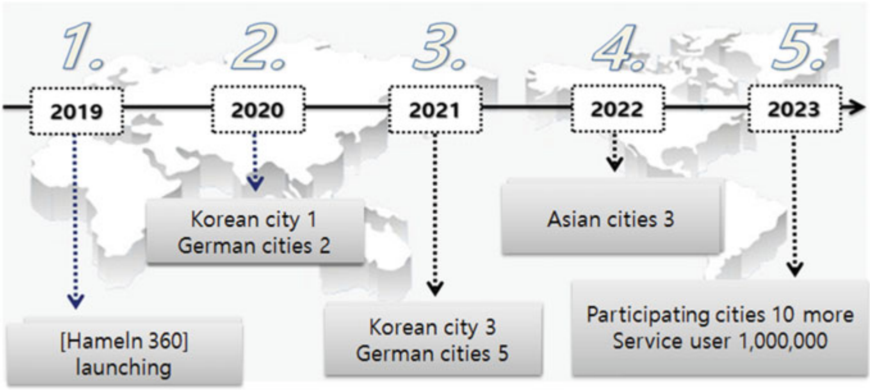

Fig. 12 Business steps to Global Märchen Platform

Virtual Reality in Lomonosov Moscow State University Interdisciplinary Research Illustrated by Moscow Bely Gorod Area Historical Reconstruction Example

Leonid Borodkin, Lemak Stepan, Margarita Belousova, Anna Kruchinina, Maxim Mironenko, Viktor Chertopolokhov and Sergey Chernov

Abstract This article is devoted to numerical optimization of three-dimensional user interface for virtual reconstruction of 16–18th centuries historical Moscow Centre landscape. Archaeological data was used to develop and visualize multiperiod reconstruction. We integrated the virtual reality solution based on the head mounted display and the motion tracking system. Interface elements should be placed near interactive objects (historic buildings). We need to optimize interface's three-dimensional design to be operable by different sized and shaped users. Uncommon and unpredictable shapes of historic buildings used as restrictions for interface elements placement add more complexity to the optimization task. We chose the sum of user's hand transition time from one interface element to another as an optimization functional. User's hands sizes, interactive object's position deviations, restrictions for interface elements' placement was used as perturbations. The expected result of our project is the complex dynamic historical information platform, aimed to visualize a historical landscape in various time sections.

Keywords Virtual reality · Historical reconstruction · Interface · Optimization · GIS · Virtual archaeology

1 Introduction

The historical basis of the project is aimed to combine data from numerous local studies on the evolution of the historical urban landscape of the Moscow center and

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to create its holistic virtual reconstruction. We have processed a big data set which characterizes the landscape changes (natural and man-made) of the Bely Gorod (White City) of Moscow at the turn of the Middle Ages and New Time. This city area initially represented by disparate settlements was transformed first into the city united by fortress walls and at a later date into a regular New Age's city with its natural topography, the parcel of quarters, the typology of property development. Moscow received a new impetus for development, based on the application of advanced virtual reality (VR) technologies.

The natural landscapes of the Eastern part of the White city differed in contrast. The edge of the moraine hill passed into the slope, which was opened by the amphitheater in the direction of the Kremlin. At its foot lay on the banks of the Moscow river Vasilievsky meadow was located. Landscapes of this type began to develop only XIII–XIV centuries. Archaeological pits and excavations between the streets of Maroseyka and Solyarnka studied 52 points, of which 30 found the initial level of occurrence of soil XII–XIII centuries, and installed the power of the cultural layer—more than 2 m on a hill and about 1 m—on the slope. On the basis of these data, taking into account the peculiarities of the layer occurrence in different parts of the relief, the paleorelief reconstruction was performed. Studies of paleosols have shown that in the XIII century the hill was forested, and the slopes are meadows and woodland that gave the area the name "kulizhki" (small meadow in the forest).

The difference between the levels of the pottery and the Church is 18 m—hence the old village stood on the slope. Such a layout is not similar to the cities of Western Europe or the cities of the East and rather resembles the late Byzantine Ohrid and Mystras. In the XVI century on the site of meadows, forests and gardens there were urban areas, which in 1585–1593 were protected by a stone wall, laid along the line of the modern Boulevard ring. This city, which is depicted on the surviving plans, also had a great originality—residential yards were then in the center of the estates, and not along the streets. All the wealth of images of the historical landscape, the layout of the city at different stages of its development, the authors plan to convey in the form of visualization.

The basis of all historical research is the sources. Working with them involves the systematization and the development of a hierarchical structure. All historical sources will be converted to the reconstruction verification module. All monuments are accompanied by a group of sources for every period. During this reconstruction we are faced with a mismatch of data in the sources. For this situation, we developed two approaches. The first is medium position of landscape height and medium position of building points, the second is a variable presentation of height solution. Researcher is able to activate all variants.

Size, detalization and scale are main options for correct immersive representation of data in virtual reality environment. Common approach is separation of sources by type or period. This system works with the traditional form of interaction, but it looks cumbersome and clumsy when used with immersion technologies, which require the development of their own representation mechanisms, which, moreover, have a unique opportunity to go beyond the 2D format. It becomes possible to use 3D environment for storage, organization of the access system and work with different blend modes and combining sources and interactive models.

The expected result of our project is the complex dynamic historical information platform, aimed to visualize the historical landscape in the three time sections and to provide conditions for VR/AR representations of historical urban environment.

2 Virtual Reality Simulation

The virtual reality Cluster the Lomonosov Moscow State University (MSU) created hardware and software to apply virtual reality technology for testing and modelling of interactive virtual historical reconstructions. Realistic simulation experience was achieved using deep feedback that activates a large amount of the person's biological sensors, including vision.

To achieve realistic visualization, MSU VR Cluster in cooperation with Total Vision ltd. developed the 2.5K virtual reality head mounted display (HMD).

The input to the visualization system gives information about the current user's mathematical model state and its surrounding objects, which allows us to simulate an interaction in real time. One of the HMD characteristics is a total covering of the user's vision field and real environment replacement by a virtual simulation. This consists of using the user's motion tracking system to transfer real person motion to a virtual space (cf. Bugrov, Lebedev, & Chertopolokhov, 2014). That what is called mixed reality.

The mixed reality system is a hardware and soft-ware suite accomplishing a visualization function of nearby condition for the user with the ability of person's motions tracking and transferring these motions to a virtual space. The technology creates absolute physical presence illusion for the person inside the virtual space.

During the mixed reality complex development, the problem of interaction with virtual interface elements becomes one of the most pertinent.

Each object of the virtual reconstruction is provided with reference information and with interactive elements that allow to open the Menu, to change the object state or to get the access to the historical source. The task can be conditionally divided into two tasks: the location of the information interface elements and the location of the interactive elements.

Despite some difference between information and interactive elements, this article suggests the general approach to the search of the efficient position for both of it.

3 Interface Numerical Optimization

3.1 Core Task

The location of the interface elements in three-dimensional space doesn't suppose the empirical approach to the task unlike the two-dimensional interface on the computer screen where Fitt's Law (cf. Fitts, 1954) can be applied. This is due to the new virtual reality possibilities to locate the elements in space without any reference to physical objects.

For example, if we consider a cube 0.5 m in size as the feasible space for the location of the interactive elements, the positional accuracy in virtual reality is 1 cm, we will get about 10^{10} experiments for two interface elements without any regard to the possible human parameters and other deviations. At the same time, the height and the arm length of the user influences the convenience of using the virtual interface the most. Similarly, various models that close the view complicate the visual tracking task.

In this article we present the method, that considers all these disturbing factors and generates the priority zone for the interface elements location.

The task of the interface elements' location optimization . For simplicity the interface element will be considered as a point (interface elements are supposed to be considered as closed sets).

Suppose there is a dynamic system that describes the eye or hand movement (system examples will be described further):

$$\dot{x} = f(t, x, v), \tag{1}$$

where $v \in V$—vector of perturbed variables and parameters.

In a pair of the interface elements the first element will be initial conditions and the second will be terminal conditions. The time of goal directed movement from first to second element we will consider as the quality functional for the location of the interface elements:

$$J(x(t_i), x(t_{i+1}), v) = t_{i+1} - t_i, \tag{2}$$

where $t_{i+1} - t_i$—is the movement time, defined by experiment or by time-optimal task solution.

Let us set the task of optimizing interface elements' positions (v is predefined):

$$J(x(t_i), x(t_{i+1}), v) \to \min_{x(t_{i+1})} . \tag{3}$$

It is obvious, that the trivial minimum task solution is in locating the interface elements at one point. However, in applications it is necessary to maintain some distance between the interface elements without mutual interference.

Moreover, the virtual environment imposes some restrictions as the interface elements are to be located out of the three dimensional objects.

Let us describe the imposed restrictions in the following way:

$$\gamma = \{\mu_j(x, l) \geq 0, \quad j = 1, 2, \ldots, N_\mu\}, \tag{4}$$

where γ set of the restrictions to interface elements' positions.

There can be more than two interface elements in a real task and the probabilities of the element transition may differ by pairs. Let us define these probabilities as coefficients $k_{x_i x_j}$ of every transition's weight (from $x(t_i)$ to $x(t_j)$) for the whole working time.

For virtual interfaces, it is possible to search for the optimal transition time for each pair independently of other transitions and restrictions imposed on the disposition of other elements.

As a result, if v is predefined, for N interface elements we get the task to minimize the weighed sum. It is worth noting, that the transition sequence is not fixed.

$$\begin{gathered} J_N = \sum_{i,j} k_{x_i x_j} J(x(t_i), x(t_j), v) \to \min_{x(t_m)}, \quad i = 1, 2, \ldots, N, \\ j = 1, 2, \ldots, N \end{gathered} \tag{5}$$

Here $x_m \in \gamma$—all possible locations of interface elements between which the transition takes place.

As stated above, the task will be solved for informational and interactive interfaces. However, the interactive elements can function as informational, but this beyond our work.

This work presents the primary outcomes, that will be a basis for solving the whole task. For informational elements we considered a binocular model of eye movement and the optimal transition task has been solved and confirmed experimentally. For interactive elements we have built the set of human arm reachability and have carried out a series of experiments, which are required to identify the parameters of the hand model.

3.2 Eye Motion Analysis

Stereo content reproduced in the virtual reality system is different in the fact that the working area is not limited by the image plane and the screen. When the spatial task appears, it is necessary to take binocular vision into account.

When we look at interface data element, our eyes make convergent movements to focus on the object.

The mathematical model of an eye movement usually considers only one eye. Applying this model for the coordinated movements of the both eyes increases the task order.

Transferring the gaze from one interface element to other is always implemented with a saccade—rapid joint eye motion. Here we consider the goal-directed eye movement of the eye pair as time-optimal task solution.

We will take a dynamic model based on Feldman muscle model (cf. Feldman, 1986) to simulate each eye of a pair:

$$\frac{I}{2kR}\ddot{\varphi} + \frac{\nu}{k}\dot{\varphi} + \varphi = \frac{\lambda_1 - \lambda_2}{2R}, \tag{6}$$

where ν—eye viscosity coefficient on the environment, k—muscle elasticity coefficient, λ—muscle length, φ—eye rotation angle, R—eye midradius. Within the model framework it is accepted, that only one pair of extraocular muscle (EOM) act in eye rotation in horizontal, frontal and sagittal plane. Both muscles have the same spring and viscous coefficients and various free length λ. For simplicity, we will consider the eye movement in a horizontal plane. Let's consider that each eye makes only a rotational movement around its geometric center.

The ocular muscles torque cannot change instantly. We can formalize this fact with the following equation:

$$\dot{M} = u, \ |u| \le u_*, \tag{7}$$

where M—torque produced by a pair of EOMs, control u—EOM torque. The initial and final conditions of EOM torque are calculated for each initial and final position of the eye.

The eye movement is simulated by solving time-optimal task during the transition from initial conditions to some final one.

Let us consider the task of transferring the gaze of two eyes from goal to goal. We use the solution from (cf. Kruchinina & Yakushev, 2018).

The optimal task. We denote with R and L indexes the variables for left and right eye respectively. We compose Eqs. (6) and (7) for each eye and reduce to the following:

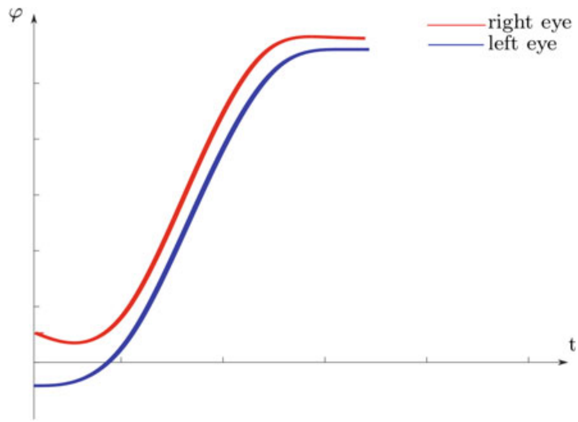
$$\begin{cases} \ddot{\varphi}_L + a_2\varphi_L + a_1\dot{\varphi}_L = M_L, & \varphi_L(0) = A_0, \dot{\varphi}_L(0) = 0, M_L(0) = M_{L_0}, \\ \dot{M}_L = u_L, & \varphi_R(0) = -A_0, \dot{\varphi}_R(0) = 0, M_R(0) = M_{R_0}, \\ \ddot{\varphi}_R + a_2\varphi_R + a_1\dot{\varphi}_R = M_R, & \varphi_L(T) = A_T + \Delta, \dot{\varphi}_L(0) = 0, M_L(T) = M_{L_T}, \\ \dot{M}_L = u_R, & \varphi_R(T) = A_T + \Delta, \dot{\varphi}_R(0) = 0, M_R(T) = M_{R_T}, \end{cases}$$
$$J = T \to \min_{u_L, u_R}, \qquad |u_L| \le u_*, |u_R| \le u_*. \tag{8}$$

Obviously, (8) can be represented in the form (1).

Applying the simulating results stated in (cf. Kruchinina & Yakushev, 2018) we get a joint eye movement (Fig. 1).

We compared the results of mathematical modelling with experimental data. We analyzed the eye movement was recorded by a high-speed SMI Hi-Speed 1250 eye movement recording system with 500 Hz frequency recording the movement of two

Fig. 1 Modelling data

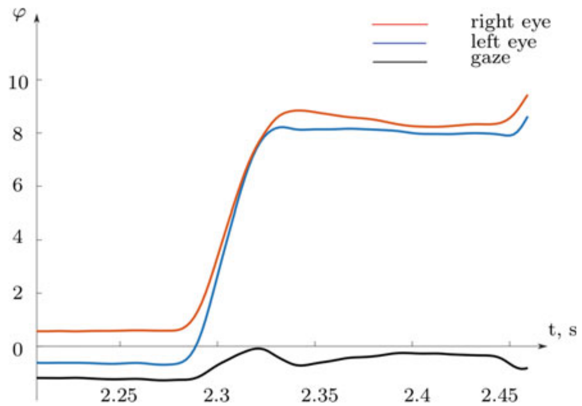


eyes. The system is a frame with forehead and chin holder with a high-speed camera fixed on it and reflective glass, an LCD screen for creating a visual stimulus, and a personal computer with software installed on it for conducting experiments and processing records.

The data represented at Fig. 2 is one part of the record from study (cf. Kruchinina & Yakushev, 2019). The study involved 9 people aged 18–22 years old with normal visual acuity, not wearing glasses or lenses; not having identified diseases of the nervous system and disorders of the organs of the inner ear. The study participants sat motionless and watched the target moving across the screen (stimuli). Series for one person consisted of 84 stimuli. The target was moving from point to point on the grid 7 × 9 in size.

Stimuli are presented one by one. The target is a white circle on a black background. In the centre of the white circle in the part of the stimuli there is a dot in 1 pixel of red, blue or green colours. Person was asked to count the number of dots of

Fig. 2 Experimental data



a certain colour. It is necessary for person not only see the target that appeared, but also look exactly at it.

The record on Fig. 2 shows the graphs of the rotation angles of right and left eyes, as well as the difference between them. Note that in the middle of the saccade the difference between the eye rotation angles is almost zero. We can conclude about the applicability of the model.

The perturbations of the initial conditions suggested in (cf. Kruchinina & Yakushev, 2019) could be applied. This way we can use such eyes motion model for the interface testing.

3.3 *Restrictions Set for Interface Elements*

For goal-directed movements of eyes and hand are usually applied time-optimal tasks. Both tasks are quite close, but restrictions for interactive elements have more complexity. Many possible hand positions, describing restrictions set (4) for interactive interface elements, were built.

Arm geometric model description. The hand parameters and the motion model are recorded using the assumption that the shoulder is fixed. A fixed coordinate system is introduced with a start at the centre of rotation in the shoulder joint, the Ox axis is directed forward from the person, the Oy axis is directed left, the Oz axis is directed vertical up.

The hand is simulated by a three-link mechanism. Links are connected by cylindrical joints. The axis of the shoulder joint is fixed. The following are taken as generalized coordinates: the angle between the forward direction and the link α_0, the angles between the links and the horizontal, respectively α_1, α_2. The following notations are also used: links length are l_0, l_1, l_2, masses are m_0, m_1, m_2, central moments of inertia is I_0, I_1, I_2. We introduced the coefficients that specify the relative position of the link mass centre on its longitudinal axis, k_0, k_1, k_2, defined by the equalities:

$$k_i = \frac{p_i}{l_i},$$

where p_i—distance from i-joint to mass centre.

Reachability sets for the arm. We used data from the book (cf. NASA, July, 1995) to construct the reachability set for hand links. Table 1 lists the restrictions for allowable angles when rotating around different axes for most people.

Let us introduce the angle s_1 as the vertical flexion shoulder angle, s_2—horizontal flexion/extension, the first link length—l_1.

Then the coordinates of the end of arm $(x_1, y_1, z_1)^T$ will be expressed as following:

$$(x_1 y_1 z_1)^T = (l_1 \cos s_2 \sin s_1, -l_1 \sin s_2 \sin s_1, -l_1 \cos s_1)^T. \quad (9)$$

Table 1 Allowed rotation angles

Rotation description	Angles' boundary values (°)
Horizontal shoulder abduction	192.9
Lateral shoulder circumduction	85.8
Medial shoulder circumduction	130.9
Vertical shoulder flexion	217.0
Vertical shoulder extension	87.9
Forearm flexion	165.9

The recorded earlier restrictions to the shoulder angle position from Table 1 and Eq. (9) further are used to construct the first link reachability set (Fig. 3) with the Wolfram Mathematica to look through all possible angle configurations with 5° step for each angle.

Let us introduce moving coordinate system $Ox'y'z'$ with the center in the end of the first link, where the axis direction Ox', Oy', Oz' with $s_1 = 0$, $s_2 = 0$ matches the coordinate system axis direction $Oxyz$. The angle e_1 matches the vertical forearm flexion angle, e_2—lateral-medial shoulder flexion angle, the second link length—l_2.

Then the forearm end coordinates $(x_2', y_2', z_2')^T$ in this coordinate system will be the following:

Fig. 3 Example of the virtual reality historical reconstruction and its interface

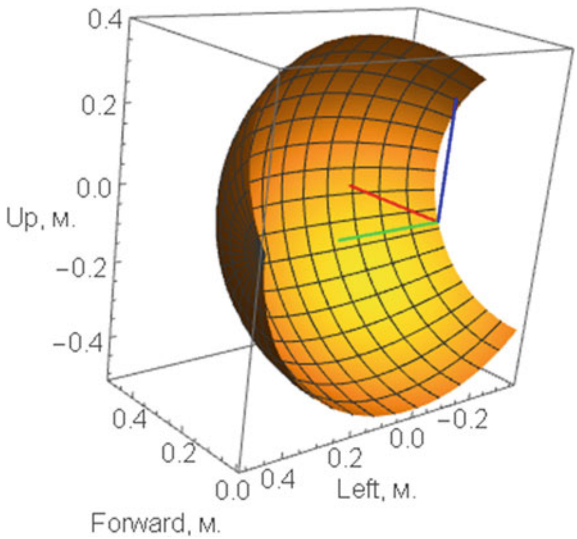


Fig. 4 The reachability set

$$(x_2', y_2', z_2')^T = (l_2 \cos e_2 \sin e_1, l_2 \sin e_2, -l_2 \cos e_1 \cos e_2)^T. \tag{10}$$

With the help of (10) we got Fig. 4. Here is shown the reachability set for the second hand link in the coordinate system $Ox'y'z'$ similar to the construction for the first link.

Let us write the coordinates for the second link to build reachability set for the forearm end in the coordinate system $Oxyz$:

$$\begin{pmatrix} x_2 \\ y_2 \\ z_2 \end{pmatrix} = \begin{pmatrix} l_1 \cos s_2 \sin s_1 + l_2(\cos e_2 \cos s_2 \sin(s_1 + e_1) + \sin s_2 \sin e_2) \\ -l_1 \sin s_2 \sin s_1 - l_2(\cos e_2 \sin s_2 \sin(s_1 + e_1) - \cos s_2 \sin e_2) \\ -l_1 \cos s_1 - l_2 \cos e_2(\cos s_1 \cos e_1 - \sin s_1 \sin e_1) \end{pmatrix} \tag{11}$$

Figure 4 illustrate the example of form of the reachability set for the hand (forearm moves, upper arm and shoulder are fixed).

The formula (11) shows how we can compute the set for the interface object's placement (4) when l_1 and l_2 are determined, interface objects should be placed inside this set. We must re-compute it for every $v = (\Delta l_1, \Delta l_2)$.

3.4 Disturbed Task of Interface Optimization

In the first part of this article we state the optimization task with defined parameters of the system (1).

For each object in the virtual scene, the object itself is static, but the parameters of the person (user) may differ significantly from the initially selected ones.

It is possible to use the parameter identification algorithm in real time and solve the interface optimization problem for each user considered in the first part of the article. However, this can be done only for a small number of interface elements and with significant restrictions on their relative position.

The optimal arrangement problem of interface elements becomes more difficult if it is impossible to carry out the identification, since it is necessary to take into account the parameters of the worst position

Alternative approach is game theory approach (cf. Lemak, 2015). Indeed, let the lengths of the links, the masses, etc., be disturbing. We will consider the relative position of the interface elements as controls. As a functional J is the weighted sum of transition times.

If the player responsible for the disturbances tries to maximize the functional, and the player responsible for the controls minimizes, then we get the antagonistic game Γ.

We will consider the minimum of the controls from the maximum of disturbances from J as an estimate of the quality of the interface:

$$\min_{x(t_m)} \max_{v} \sum_{i,j} k_{x_i x_j} J(x(t_i), x(t_j), v) \tag{12}$$

To find the optimal solution, it is possible to use dynamic programming methods (cf. Bellman, 1957). Due to the large number of variables, the problem is a large-scale problem and requires computation of a large amount and memory resources.

4 Conclusions

The article gives a statement of the problem of optimizing the spatial interface of virtual reality and gives examples of solving internal problems.

This method was used in our research allows us to use virtual reality interface for deepen understanding of the multidimensional influence of the anthropogenic factor on the evolution of the historical urban landscape. The proposed algorithm provides higher accuracy and quality of displaying human movements in virtual reality. It helps to immerse a user in the historical urban environment.

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Simplifying Electronic Testing Environment with SLAM Based Handheld Augmented Reality System

Carlos Arias, Andoni Arregi, Fabian Schriever and David Martinez Oliveira

Abstract Current electronic testing measurements during embedded software development lack simultaneous multiple real-time measurements with location-specific information. To address this problem with a focus on electronic subsystem testing in the space industry an Augmented Reality (AR) solution is presented in form of a technology demonstrator. This Simultaneous Localization And Mapping (SLAM) system based on the Handheld Augmented Reality (HAR) concept provides an affordable zero-time installation augmented reality system that blends simultaneously multiple real-time measurements displayed exactly where they are measured. The system is composed of a handheld device and so-called Smart Probes, or miniature Bluetooth Low Energy (BLE) devices attached electronically to the measured specimen. This system may, with further development, become an alternative to a multimeter, an oscilloscope, and a logic analyser.

Keywords Handheld augmented reality (HAR) · Smart probes · SLAM · Electronic measurement

1 Introduction

Electronic components are present in most domestic and industrial products and their related global export value of electronics and electrical engineering grew over 10% yearly in 2017–2018 (International Trade Centre, 2019). New technology drivers

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like Internet of Things (IoT) applications will “increase dramatically” (Höller et al., 2014, p. 11), since the number of smart connected home appliances is forecasted to be 700 million units in 2020 (IHS Markit, 2015). Therefore, it is expected that the related electronic development activities such as design and testing will increase in the coming years.

Electronic design and testing, especially together with embedded software development requires an iterative process (National Research Council, 2001, p. 184). Developing an automatic test system to check system functionality is only economically viable after the product design is concluded and its production starts. In fact, these automatic test systems merely verify whether electronic subassemblies are manufactured and integrated according to the design, leaving an assessment of the system design aside.

During embedded software and electronics development phases, measurement tools e.g. multimeters, oscilloscope and logic analysers are used to measure and monitor electronic signals. When the tested system achieves a certain level of complexity, the number of measured signals increases quantitatively. Used measurement tools tend to be grouped and located far enough from measurement spots, so that location-specific context is lost. Considering that “human attention is limited”, adding an extra cognitive task consisting on mapping a measurement from a multimeter with the spatial location of the pinned location on the electronic system, can easily increase the cognitive load (Haapalainen, Kim, Forlizzi, & Dey, 2010), inducing error prone situations.

Augmented reality (AR) superimposes a virtual information environment on top of a live picture of the user’s surroundings (Craig, 2013, p. 15). AR technology enables new business models as well as firm value creation (Ro, Brem, & Rauschnabel, 2018). Internal firm value increases if an internal process is improved. AR technology may improve assumed for years inefficient procedures (e.g., needing two persons to measure two different measurements with two multimeters simultaneously). As a technology demonstration, GTD developed an AR application that avoids the loss of relevant context information about the physical origin of measurements in electronics and embedded software development environment.

2 Background

2.1 Synoptic Diagrams

Supervisory Control and Data Acquisition (SCADA) systems are the backbone of many industrial control systems, where the different modules to supervise and to control are scattered over some meters or even kilometres depending on the industrial application. Often there is a main control room, where operators manage and command the whole system. Even though operators are intensively trained to perform these tasks, the amount of information gathered at the main control room is not manageable by operators in raw form. Synoptic diagrams are commonly used to display in real-time only main information gathered on the different modules, blended with the location-specific information of the unit, where such information is measured. The context information included at SCADA synoptic diagrams provided would be of great benefit for developing and testing embedded electronics activities.

2.2 Space Industry AIT/V

During project phases C/D in space industry as defined in ECSS Standard (ECSS, 2009, pp. 24–25), Assembly, Integration, Test, and Verification (AIT/V) activities are carried out. Engineers build breadboards, engineering, and flight models for instruments and satellite platform equipment in very small series or even singular batches with high quality requirements. During electronic development of these subsystems and subsequent testing and integration with others, an iterative process with multiple modifications and design corrections takes place. The complexity of the system under development requires a considerable context knowledge and, as several persons are involved during this process, detailed testing procedures are developed to facilitate testing. The effort required to maintain these testing procedures updated while undergoing an iteratively changing development process is difficult to manage even if fast-paced project approaches are targeted (Chartres, Sanchez, & Hanson, 2014).

2.3 AR in Space Industry

Several augmented reality research projects have been carried out in space industry such as WEAR, Portable AIT Visualizer, mobiPV, EdcAR funded by the European Space Agency (ESA) as well as initiatives like Sidekick, OnSight funded by National Aeronautics and Space Administration (NASA). These projects focus mainly on procedural guidance use cases acting as virtual assistant that supports astronauts with complex procedures for maintenance and mission specific purposes aboard the International Space Station (ISS) (Markov-Vetter, Millberg, & Staadt, 2013), but other domains such as AIT/V have been identified (European Space Agency, 2014, p. 10).

2.4 SLAM Based HAR

Thanks to recent technology developments enabling Simultaneous Localization And Mapping (SLAM) based Handheld Augmented Reality (HAR), some adoptions barriers of augmented reality have disappeared or drastically been reduced. The use of

Table 1 Electronic measurement tools

	Benefits	Drawbacks	Price
Multimeter	Fast response Fast setup Light weight	Only discrete measurements Both hands needed Measurement not stored	5–80 €
Oscilloscope	Normal setup 2–4 multiple signals Time related measurements	Both hands required Limited to 2–4 signals Expensive and cumbersome	200–800 €
Logic analyser	8–24 multiple signals Time related measurements	Long setup time and effort Only for digital signals	60–600 €

ARCore[1] or ArToolkit[2] together with a common smartphone or tablet used as hand-held device eliminates the environment set-up calibration, since "SLAM tracking (…) can instantly generate the AR environment without any prior knowledge of the real environment" (Polvi et al., 2013).

3 Motivation

3.1 Electronic Measurement Tools

During electronic design and testing as well as during its embedded software development digital multimeters, oscilloscopes, and logic analysers are of common use in prototype design laboratories. Table 1 presents some characteristics of measurement tools used in common electronic laboratories.

Following merely the analysis presented in Table 1, most electronic laboratories would buy some logic analysers and oscilloscope per desk and few multimeters to fulfil the measurement needs effectively, if the available budget were enough. Instead, there are some multimeters per desk because of its fast setup and response time and limited oscilloscopes and logic analyser per laboratory. Additionally, multimeters provide a sort of location-context, if the probes are hold with the technician's hands (and not with crimping mechanism).

3.2 Photobioreactor Project

For the Photobioreactor at the Life Support Rack (PBR@LSR) experiment (Detrell et al., 2018) launched on 6th April 2019 to the International Space Station (ISS), GTD developed the electronic box that receives the experiment sensor measurements

[1]https://developers.google.com/ar/.

[2]https://www.artoolkitx.org/.

and commands its actuators. Although the developed electronic which comprises five customized Printed Circuit Boards (PCB) is less complex than (Chartres, Sanchez, & Hanson, 2014) the amount of data produced by the Ground Support Equipment (GSE) connected to the electronic boards is considerable and error prone susceptible. The loss of context information can lead to errors regarding the right source of information even for involved personal and considerable time effort is lost by misunderstandings about sensor position in the system or by following difficult test procedures, which may saturate the cognitive load of engineers.

3.3 AR Application

GTD identified a specific use case, where the use of augmented reality could solve the above-mentioned problem. The main goal was to develop an affordable, easy-to-use and with zero-time setup effort system that enables AIT/V engineers to visualize real-time measurement data, collected from smart probes in an augmented reality environment. The proposed system should aim use of common Commercial Off-The-Shelf (COTS) components such as conventional smart phones or tablets as handheld device and affordable small PCB incorporating state of the art technology in commercial electronics industry for the smart probes. With the technical support, project supervision, and funding by ESA, a Virtual, Intuitive, Real-Time, User Assistant (VirtUA) augmented reality system has been developed. Thanks to AR, benefits of current measurement tools of Table 1 can be combined enhanced with location-specific context of the system under test (see Fig. 1).

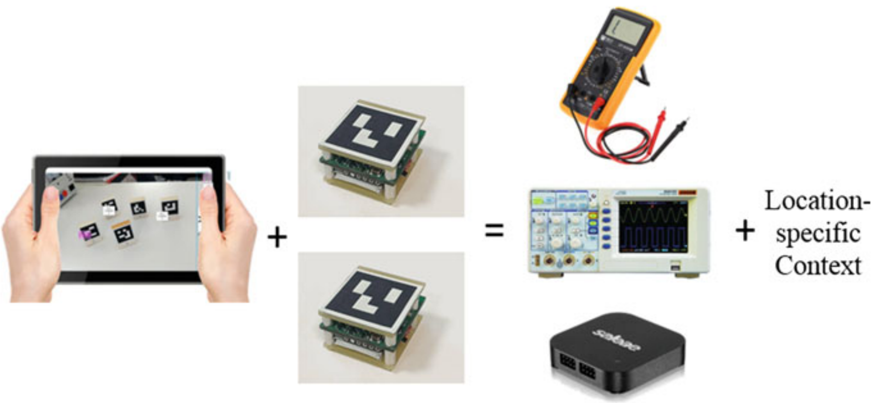

Fig. 1 System concept application

4 Performed Work

Starting from a Technology Readiness Level (TRL) 3 defined as "Analytical and experimental critical function and/or characteristic proof-of-concept" and targeting a TRL 6 "Model demonstrating the critical functions of the element in a relevant environment" to overcome the "valley of death" (ECSS, 2017, p. 16), the system development has been divided in two main streams: Smart Probes and the software running on the handheld device.

4.1 Smart Probes

A Smart Probe is defined as an electrical measurement tool that measure voltages, sends the measurement through BLE, and can power sensors without external power supply. Additionally it is compatible with I^2C bus sensors and allows different voltage ranges.

Smart Probes development has evolved and adapted some existing hardware approaches used currently for medicine technology for the purposes of VirtUA. JS Electronics, the subcontractor and partner of GTD for electronics development already had experience in building BLE based medical devices for electrocardiogram measurements thus, this development has brought these designs a step further.

The miniaturization effort has brought the current prototype (see Fig. 1) to a size of ca. $3.3 \times 3 \times 2$ cm and a mass of 22 g, including a 100 mAh LiPo battery for the first prototype. The second produced batch is thinner achieving $3.3 \times 3 \times 1.4$ cm and same weight using a battery with more capacity (450 mAh).
A Smart Probe is composed of following functional modules:

- Microcontroller with integrated BLE based on Cortex-M4F ARM series.
- Analog frontend.
- Power supply module allowing multirange measurements and sensor power supply.

The external interfaces included in the smart probe are:

- BLE data interface.
- Micro USB type B charging socket.
- Voltage multirange up to 40 V.
- I^2C bus (CLK and SDA pins) for some sensors.
- Power voltage supply for sensors.
- JTAG programming interface.

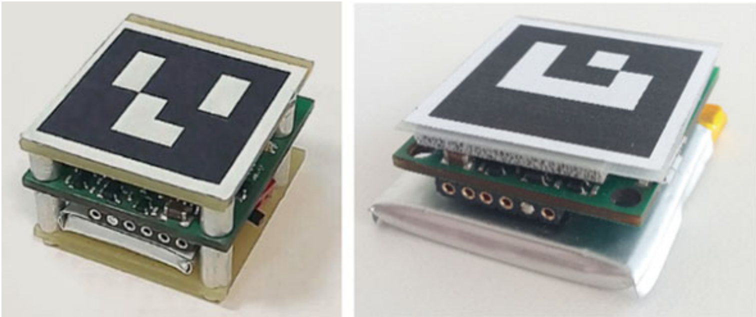

Fig. 2 First and second batch of Smart Probe

4.2 Software

The software developed for VirtUA consists of three computer software items:
Software running on the handheld device
User Interface has been developed using following COTS tools:

- Unity3D: providing the base of the Android application, User Interface capabilities handling a 3D environment.
- OpenCV + ArUco: providing sporadic (1 Hz) fiducial marker detection.
- ARCore: Allowing points detection in 3D space and real-time tracking of them (SLAM feature).

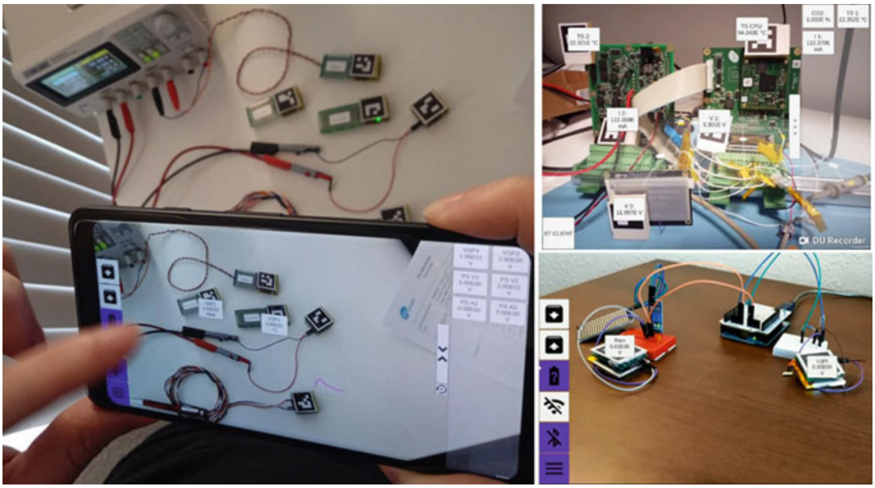

Fig. 3 User interface examples

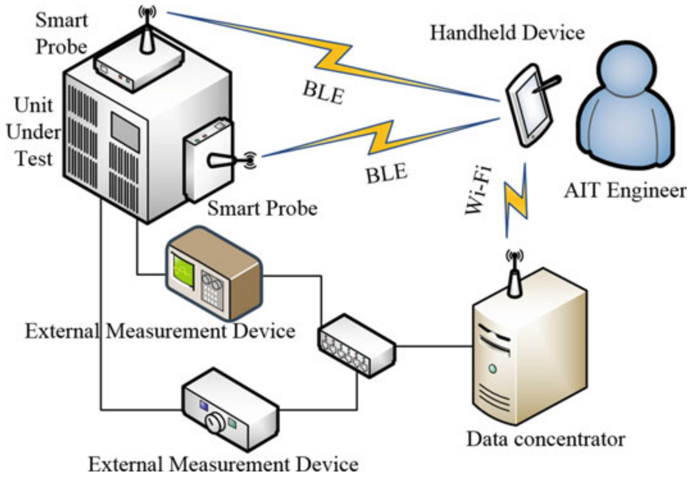

Fig. 4 System overview

The handheld device logs internally all received data from the smart probes and the external computer (optional), which helps further investigation of measured data and of the system itself.

Embedded software running on the smart probe

It reads measurements directly from analogue voltage measurements or from one of the supported I^2C sensors and sends JavaScript Object Notation (JSON) datagrams via BLE. Additionally, it monitors the battery status and reacts to commands sent by the handheld device (e.g., enable sensor supply or change voltage measurement range).

Concentration software running on a PC (optional)

This software programmed in Python allows to forward measurements from external measurements devices (e.g. oscilloscope) to the handheld device. Additionally it is also possible to command such external devices from the handheld device (e.g., switch on a power supply unit) if they are connected to this computer (see Fig. 4).

4.3 Other Features

To keep VirtUA an extensible platform, a data concentrator software has been developed. The goal of this concentrator is to centralize other measurements and data obtained from sources external to VirtUA (e.g., a power supply) that contain relevant information to be shown together within the AR environment.

With the extensible approach in mind, generated logs at the handheld device can be easily plotted using a web-based tool. This is a powerful method to analyse and

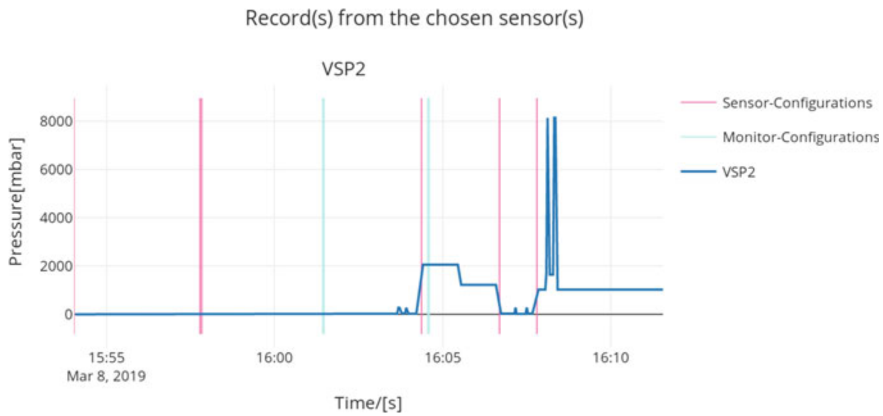

Fig. 5 Retrospective measurements analysis

reproduce measurements once the engineer or the system under test is not available in the laboratory. A generated view is depicted in Fig. 5.

5 Achieved Results

A HAR system has been developed which shows localized measurements sent by Smart Probes, placed on the electronics or equipment being assembled, integrated and tested. The application is an affordable smartphone or tablet based augmented reality system accompanied by small Smart Probes to measure physical quantities on the equipment under test. The main challenges related to the product development have been:

- The use of common smartphones and tablets for an AR system with real-time localization and tracking capability without sacrificing a high framerate. The number of available compatible devices is more limited than expected due to the untrue information provided by Google when searching for devices capable of running the ARCore SW for 3D tracking purpose. Although this software should be usable on many current devices, Google blocks currently its use to only a subset of "certified" devices allowed by Google. This has been a hurdle in the development of VirtUA, since one of its main purposes is to enable the use of AR technologies on commodity devices, though the number of supported devices has increased lately.
- Deployment of the AR system as a simple Android application (APK file) without the need of additional databases and "ad hoc" information to be introduced for each specific use.
- Plug-and-play capability of the system (i.e., no need to "pre-scan" the laboratory and no previous specific "placement" of relevant information is necessary).

- Sufficient miniaturization of the Smart Probes to enable an easy way to attach them to breadboards and other electronics both when the use of VirtUA was previously planned and when it was not.

VirtUA system requirements and performance have been validated using simultaneously five Smart Probes over 5 h generating about 10 MB of data and almost not affecting the battery (using the 100 mAh battery).

6 Validation and Usability

Use case based evaluations have been carried out on engineering model electronics from an ISS experiment and on several electronic breadboards at different production and testing phases available at the electronics manufacturer partner JS Electronics.

These evaluations have pointed out some concrete features of the smart-probes and the AR visualization that must be fine-tuned to prepare VirtUA as a product.

A usability assessment has been carried out by GTD using HAR Usability Scale (HARUS) evaluating both *Manipulability* and *Comprehensibility Measures* (Santos, et al., 2014) obtaining 79.95 points out of 100.

6.1 Features to Improve

Both main elements of VirtUA, Smart Probe and the Hand-held device have shown designed features that are improvable.

- Improving measurement display notation.
- Adapting size of controls to the handheld device size.
- Some configuration steps should be more "drop-down" based instead of expecting free user input.
- Improve size and colours (based on background colour) of displayed measurements.
- Improve Smart Probes battery charging mode monitoring.

6.2 Future Features

After evaluating the use-case based evaluation feedback, some missing features have been identified, which would better cover most of the use-cases VirtUA is meant for:

- Define a proper housing for the Smart Probe.
- Define an appropriate clamping mechanism for the Smart Probes.
- Extend the number of I^2C drivers for popular sensors to reduce adoption barriers.

Other factors that may influence a broaden adoption of the presented AR application should be considered in the future and assessed accordingly. Utilitarian, hedonic, and symbolic benefits as well as perceived risks (privacy and loss of autonomy) may have, if well addressed, a significant effect on technology adoption (Rauschnabel, He, & Ro, 2018). Hedonic benefits may enable VirtUA as a teaching support tool (e.g., engaging young students in electronics subjects). Generated JSON data has no directly private information (only measurements), thus it should not have major influence. Nevertheless, if properly configured, user information might be included (e.g., X person was performing Y measurements at Z time). Depending on the information obtained, other corporate legal issues may appear (e.g., temperature sensor indicates that room temperature at that time was over the legal limit, so no employee should be working at that room).

7 Conclusion

A technology demonstration of an affordable AR solution based on common available hardware with a plug-and-play philosophy has been built which can be used as an assistant for small equipment/electronics AIT/V activities. Following use-case description summarizes a positive outcome of this technology:

- An easy to use AR system: Place the Smart Probes on the electronics, switch the handheld device on, run the application, and it displays localized measurements shown on the screen once the Smart Probes are pointed.
- A focused view of the AIT/V activity carried out: 5 Smart Probe measurements plus some further external measurement devices are displayed on the screen, not dozens of measurements. This avoids misunderstandings about e.g., sensor names (Is this measurement "Temp. 1" or "Temp. 4"?).
- The AIT/V engineer gets a fully reproducible log of the measurements she observed. Common Electrical GSE systems also provide extensive logs but in VirtUA the interest relies in the association between the log data and what the engineer observed in the AR environment, as this kind of information is often not easy to recall by engineers from a huge pile of log data.

The developed system is still a prototype and further development steps need to be carried out. Improvements are still required in terms of user experience and usability, requiring more and different use-case validations. GTD will use VirtUA as measurement tool in future relevant embedded software and electronics development, so that targeted TRL 6 can be proved.

Additionally, the outcome of this project is applicable in other industries than space, as long as measurements during electronic prototyping are needed. This could be the case for electronics education and training, medical devices development, aerospace, and automotive electronics. Hedonic features might be determinant for this adoption.

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How Real Do You See Yourself in VR? The Effect of User-Avatar Resemblance on Virtual Reality Experiences and Behaviour

Marnix S. van Gisbergen, Ilay Sensagir and Joey Relouw

Abstract The aim of this study was to gain better insight into the effects of high and low avatar- owner resemblance on spatial presence, engagement, naturalness and negative effects regarding the user experience in an immersive virtual environment. Participants, between 18 and 32 years old, needed to walk on a 60 m high broken pathway in either a condition in which the shoes in VR matched the shoes they were wearing in reality (high resemblance condition) or not (seeing only generic shoes in a low resemblance condition). The results showed no differences between the conditions, despite that participants within the high avatar- owner resemblance perceived a higher similarity between themselves and their digitally displayed shoes and all liked to customize their shoes in VR. This results indicates that it is not a requirement to develop high avatar-owner resemblance in highly immersive virtual environments in which extreme situations are presented which trigger psychological arousal such as stress.

Keywords Virtual reality · Resemblance · Avatar · Personalization · Experience

1 Introduction

In this study, we examined the effect of resemblance between the user of and the avatar inside a virtual reality (VR) environment on experience and behaviour. Researchers have argued that VR has the potential to captivate and engage audiences (Barab, Thomas, Dodge, Carteaux, & Tuzun, 2005; Yee & Bailenson, 2007). VR can be defined as a unique combination of technologies (sensory, interaction, control and location) which is able to create a feeling of 'being there'. Often a more realistic experience compared to other media (Van Gisbergen, 2016). These technologies make it possible for the user to observe VR and be digitally represented inside the VR. Usually, a virtual representative is used from the perspective of the user like an avatar. An avatar is a (partially- or full-body) digital representation of the user and is

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controlled by the user (Bailenson & Blascovich, 2004; Jerald, 2015; Whalen, Petriu, Yang, Petriu, & Cordea, 2003).

Avatars can range from simple non-interactive illustrations or pictures in 2D to fully interactive articulated 3D representation shaped like the body and or mental representation of the user (Biocca, 2014). Avatars not only give an indication about the position, location and body posture of the user, but might also help to increase the VR experience (Steed, Pan, Zisch, & Steptoe, 2016). And indeed in many games and simulations users spend time selecting and designing their Avatars accordingly to their own appearance (Ducheneaut, Wen, Yee, & Wadley, 2009; Lim & Reeves, 2009; Vasalou, Joinson, & Pitt, 2007). This creation of a digital self-representation may increase user enjoyment and motivation in a game and in VR (Bailey et al., 2009; Lim & Reeves, 2010). Due to technical innovations in simultaneous depth detecting and human motion tracking, it also has become easier to design and create a more realistic (self) Avatar inside VR (Maimone & Fuchs, 2011). However, realistic avatars are complex and costly to create (Larson, 2015). As such, the benefit of experiencing the VR environment with a personalized avatar must outweigh the energy and costs of creating such a personalized avatar.

LaValle (2017) claims that it is relevant to investigate which level of realism is required regarding avatars. Specifically the amount of resemblance between the user and the avatar. Theories provide contradictive predictions. The Uncanny Valley, for instance, postulates that a too high level of realism of avatars in VR, increase the perceived "creepiness" of the avatar (LaValle, 2017; Mori, 1970; Seyama & Nagayama, 2007). However, users with avatars that are similar to themselves might experience a better identification and self-awareness and thus enjoyment. A digital self (as an avatar) might connect the physical body to the digital self and in doing so increase presence (Gee, 2003; McCreery, 2011; Tromp et al., 1998). The more inclusive and simulative the VR is, the higher the possibility to transform oneself within it in relation to the physical world and consequently, the higher the sense of presence might be (Bente, Rüggenberg, Krämer, & Eschenburg, 2008; Nowak & Rauh, 2005; Streuber, de la Rosa, Trutoiu, Bülthoff, & Mohler, 2009; Slater & Wilbur, 1997). The environment becomes more personally relevant for the user when supporting identification through the avatar (Biocca, 2014). Consequently, due to the positive effects, the range of customization offered for avatars is increasing (Ducheneaut et al., 2009; Jin & Park, 2009).

Previous studies do not provide a clear answer to whether Avatars need to be highly realistic in order to create an immersive experience in VR (for an overview see also Van Gisbergen, Kovacs, Campos, van der Heeft, & Vugts, 2019). Several studies indicate positive effects of a realistic avatar on feelings of presence and engagement (e.g., Biocca, 1997; Koda & Maes, 1996; Lee, 2004; Slater, Usoh, & Steed, 1995; Slater, Usoh & Steed, 1994; Slater & Wilbur, 1997; Wexelbat, 1997). However, other studies also indicate that trying to achieve a higher level of realism, or creating a higher level of anthropomorphic avatars, can also reduce feelings of presence and engagement (e.g., Jo, Kim, & Kim, 2017; Nowak, 2004). Especially when the avatar do not show a correct facial expression or eye gaze movement (Bailenson, Blascovich, Beall, & Loomis, 2001; Bailenson, Yee, Merget, & Schroeder, 2006). A very realistic avatar raises higher expectations of users, which can lead to disappointment if these expectations cannot be met by providing sufficient realism (Garau et al., 2003; Slater & Steed, 2002; Van den Boom, Stupar-Rutenfrans, Bastiaens, & van Gisbergen, 2015).

Most of these studies focused on the level of realism, and not the level of resemblance to the user (self-representation). Avatar realism also refers to the level to which the virtual representation resembles visual and behavioural feature of the user (Kang & Watt, 2013). An avatar can differ in its degree of resemblance regarding the physical identification of the user, the appearance, and visual indication of social roles, personality, gender and behaviour (Biocca, 1997). In this study, we focus on differences in visual realism, when only part of the body is visible. Research showed that self-representation based on merely part of the body could also increase a feeling of presence (Botvinick & Cohen, 1998; Lin & Wang, 2014; Sanchez-Vives, Spanlang, Frisoli, Bergamasco, & Slater, 2010; Steed et al., 2016; Yuan & Steed, 2010). However, the effect of different levels of self-representation remains unclear. In sum, it is unclear how realism plays a role when only part of the body is presented in VR. It is challenging to identify what level of avatar-owner resemblance is required, and whether a higher VR and player experience can be reached by increasing the avatar-owner resemblance.

2 Study

The aim of this study was to measure the effect of higher avatar resemblance on VR experience, in order to provide recommendations in whether or when to invest in increasing realism in VR. We designed a between group experiment in which one group had the possibility to personalize their avatar (resemblance group), while the other group could not (non-resemblance group). For the experiment, we used a VR Vertigo game Descend, created by our game students from the game department and developers from the R&D department of Breda University of Applied Sciences. In this highly immersive game, you need to walk over a wooden 60 m spiralling broken down pathway inside an old church building. While walking down the user is able to see his feet and shoes moving over the pathway (see Fig. 1). The pathway contains gaps where bigger steps were required or where players have to balance over thin wooden beams. Additionally, participants have to overcome challenges, for instance being surprised by flying bats or by a falling church bell, while being engaged by the depth of being able to look down deep. The task of the participants was to proceed on the pathway as far as possible without falling. Missing the right step, means game over by means of a deep fall in VR.

The VR game was created using the HTC Vive 2017 headset (with 1080 × 1200 pixel resolution per eye, 90 Hz refresh rate) and two controllers which were attached on the ankles of each participant who were able to move inside a room size of approximately 15′3, 5″. The two controllers tracked and replicated the walking movements within the virtual environment (using StreamVR Tracking, G-sensor, gyroscope,

Fig. 1 The virtual reality game descend

proximity). As the shoes are the only visible part of the avatar, two conditions were created based on shoe personalization. One group could only see a generic pair of hiking boots (non-resemblance condition, see Fig. 1), while the other group was able to customize the shoes based on the shoes they were wearing (resemblance condition). To create this possibility a special room was created inside the Church where players could select different types of shoes (or socks when the type of shoe was not present) by kicking against different crates of shoes falling down and select the right colour by pressing their foot on a colour band on the floor (see Fig. 2).

We measured (a) avatar resemblance satisfaction, (b) VR experience, (c) Game Experience and (d) Realism customization liking. *Resemblance satisfaction* was measured using the Scene Realism factor items from the German VR Simulation Realism Scale (Poeschl & Doering, 2013), using five-point liker scales (1 = strongly disagree; 5 = strongly agree). Questions were formulated like "The shoes were very similar to my own shoes while experiencing the displayed environment". For both conditions Cronbach's Alpha was good to high (α *resemblance* = 0.60; α *non-resemblance* = 0.81).

VR Experience was measured using the ITC-Sense of Presence Inventory (ITC-SOPI) questionnaire (Lessiter, Freeman, Keogh, & Davidoff, 2001). This questionnaire measures four dimensions of VR experience (spatial presence, engagement, naturalness and negative effects), consisting out of 44 items using five-point Likert scales (1 = strongly disagree; 5 = strongly agree). This questionnaire is commonly used to measure VR experiences (e.g., Baños et al., 2004; Lo Priore, Castelnuovo, Liccione, & Liccione, 2003; van den Boom et al., 2015). Two extra items were

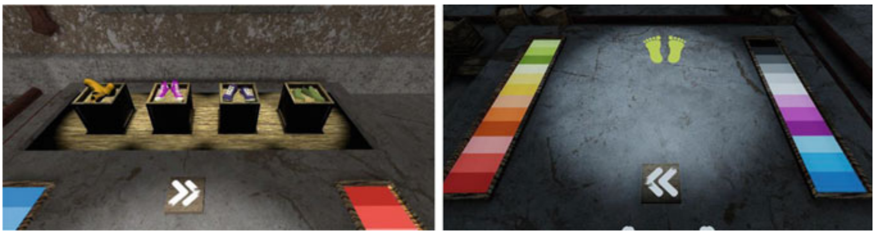

Fig. 2 The selection and design of personalized shoes within the VR game descend

included specifically identifying the negative effects concerning the displayed height within the VE. All four factors showed a Cronbach's Alpha reliable test above 0.65.

Game Experience was measured using the first factor (Core Module) of the Game Experience questionnaire (IJsselsteijn, De Kort, & Poels, 2008), using five-point Likert scales on 19 items such as immersion, flow, competence, tension/annoyance, and challenge, while leaving out items already present in the ITC-SOPI scale (α ranging between 0.62 and 0.90).

Realism customization liking was measured using questions that depended on the condition: "Would you liked to customize your shoes avatar by choosing the shoe model and the colour?" (non-resemblance condition) and "Did you like the fact that you could customize your shoes avatar by choosing the shoe model and the colour? (resemblance condition). In addition to these effects background information was measured among others age, nationality and previous experience with VR.

A total of 76 participants were recruited for the study, all being students ate the Breda University of Applied Sciences with an equal gender and age division between both conditions (between 18–35 years (M = 22, SD = 3.1). Participants were from different nationalities (43% from The Netherlands, 12% from Bulgaria, 8% from Germany and 37% other). To avoid unnatural VR behaviour (Van Gisbergen, 2016), almost all participants (85%) were familiar with VR. Participants who had not experienced VR before were first exposed to a different virtual environment, before taking part in the experiment. Participants were excluded to participate in case of acrophobia, claustrophobic, epilepsy or suffer from brain damage. Furthermore, participants with hiking boots were excluded as well, to avoid resemblance in the non-resemblance condition. The experiment took place May 2018 at Breda University of Applied Sciences in The Netherlands. The experiment took about 30 min (15 min of game play and 15 min of filling in the online questionnaire).

3 Results

The results showed that players perceive a higher similarity between themselves and their avatar, when they can personalize their avatar (Mnr = 2.18, SD = 1.23, Mr = 3.92, SD = 0.88, $t = -7.086$, $p = 0.000$). In addition, it also revealed that players like to customize their avatars to create more resemblance. Almost all (94%) liked it, or would have liked it, to customize their shoes in such a way it resembled their own shoes that they were wearing while playing.

In both conditions the awareness of the shoes was high and resemblance did not affect; (a) the awareness of the shoes (Mnr = 4.47, SD = 0.50, Mr = 4.37, SD = 0.54, $t = 0.87$, $p = 0.38$), (b) the perceived level of realism of the Avatar (Mnr = 3.74, SD = 0.70, Mr = 3.62, SD = 0.75, $t = 0.673$, $p = 0.503$) and also not the overall experience (Mnr = 4.34, SD = 0.58, Mr = 4.24, SD = 0.59, $t = 0.783$, $p = 0.436$).

The results also indicate that there is no difference in the *VR experience* due to avatar resemblance differences on all four factors: Spatial presence (Mr = 3.64, SD = 0.42, Mr = 3.78, SD = 0.48, t = −2.290, $p = 0.472$), Naturalness (Mnr = 3.62, SD = 0.63, Mr = 3.70, SD = 0.61, t = −0.552, $p = 0.582$), Engagement (Mr = 4.15, SD = 0.36, Mr = 4.15, SD = 0.43, t = 0.000, $p = 1.000$) and Negative Effects (Mnr = 2.19, SD = 0.70, Mr = 2.38, SD = 0.78, t = −1.128, $p = 0.263$).

The results only showed a high correlation between avatar-owner resemblance and spatial presence (r = 0.264, $p < 0.05$). In line with the VR experience, Avatar resemblance also did not have an effect on *game experience*. In both conditions the overall game experience was positive (Mnr = 4.2, SD = 0.42, Mr = 4.2, SD = 0.54, t = 0.288, $p = 0.774$) and negative feelings were low (Mnr = 2.1, SD = 0.77, Mr = 2.1, SD = 0.56, t = −0.083, $p = 0.934$).

4 Conclusion

The results provide some evidence that effort in creating a high realistic VR environment, by means of more resemblance of the avatar with the 'real' self, is not always needed. Of course this study only measures the effect in a typical context that might have hindered an effect of resemblance: (a) only part of the Avatar was visible (the shoes), (b) the VR experience in itself was very engaging (exciting game using fear of heights) and (c) there was only one exposure with the game/Avatar (they only played the game once) with users that do not have much VR experience in general.

A study conducted by Jo et al. (2017) indicated that users generally have a high sense of presence when using an avatar with matching outfits and higher resemblance to its owner. However, a full body representation was given in that study, and in this study, merely the shoes were replicated digitally. Furthermore, Jo et al. (2017) drew their participants' attention specifically on the avatar and in this study participants had to focus on not to fall virtually from the pathway in the environment. Or as one of the participants stated: "*When I was in, I forgot about the avatar. I was just experiencing the game*".

The results are also in line with previous research that showed that the level of realism is less important when it concerns highly immersed virtual environments created for VR exposure therapy (e.g., Diemer, Lohkamp, Mühlberger, & Zwanzger, 2016) or active dangerous situations (e.g., Van Gisbergen, Kovacs, Campos, Van der Heeft, & Vugts, 2019). The results might be beneficial for VR practitioners, researchers and developers, since non-resembled avatar representing the user are more economical to create, are less in need of resources. Especially when VE are needed in which extreme situations are presented which trigger psychological arousal such as stress, it seems that more realism (resemblance) is not always needed. Before spending costs, developers should first critically evaluate (and test) the purpose of the VE and whether there is a need for a realistic avatar. Especially for instance in the context of psychotherapy, where patients are exposed to anxiety-provoking situations and the anxiety is triggered by an highly immersive environment, time can be spend more on the user (patient) instead of the development of highly realistic Avatars.

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