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M. Claudia tom Dieck
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Augmented Reality and Virtual Reality

New Trends in Immersive Technology

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Preface

The sixth International Augmented and Virtual Reality conference was held online for the first time. For all of us, 2020 has been a challenging year with many unknowns and changes to the way we work, socialise and operate. “Online” has become the new normal for meetings and conferences, possibly and most likely changing our future behaviours towards a blended online and offline approach.

Immersive technologies will become more important and prominent, and this collection of papers highlights this trend, implications and future research directions. We hope it offers valuable insights and provides us with ideas and solutions for a future in health care, art, tourism, storytelling, marketing and retail, architecture, industrial settings and education.

Manchester, UK

Dr. M. Claudia tom Dieck
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How to Design Effective AR Retail Apps

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

Abstract Highly valued consumer experiences occur when emerging technology—such as Augmented Reality (AR)—is presented in an emotionally engaging format. Fashion retailers must understand how Augmented Reality can offer an exceptional retail experience to retain consumers in the store. By running two workshops and AR prototype experience tests, our results indicate that retailers can improve the customer experience by designing AR Apps to provide enjoyment features but focus more on helping shopping's functional tasks. Participants have a positive attitude towards AR shopping adoption, which will improve consumer satisfaction and boost purchase intention. We recommend the most effective form of AR app for fashion retail.

Keywords Augmented reality · User experience · Shopping experience · Retailing

1 Introduction

Consumers in the Millennial (born since 1982) and Generation Z (born since 1997) groups have grown up in a digital world with fundamentally different consumer behaviours from the previously dominant Generation X consumers (Kahn et al., 2018). These younger consumers seek smarter, digitally connected, shopping experiences that cross physical and digital domains (Verhoef et al., 2015). High-street—physical store—retailers are under pressure to reduce prices while delivering enhanced value to compete with electronic commerce (e-Commerce) giants such as ASOS and Amazon. With 2020s COVID-19 pandemic making e-commerce an essential part of life (Craven et al., 2020), retailers must evolve to survive. Advanced technology offers such lifelines.

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Fashion retailers are struggling to keep consumers in physical stores. Despite e-Commerce's growth, retailers still require physical stores to maintain brand value. High-street retailers must differentiate themselves in a crowded market through continued focus on experiential stores (Dover, 2019). Treadgold and Reynolds (2016) suggest that the physical store should achieve a competitive advantage on value, convenience, immediacy, problem-solving, and a superior experience.

Early AR retail applications include virtual try-on and interactive displays. These early AR systems give the consumer information on promotions, products, and locations (Bonetti et al., 2018). AR has, therefore, the potential to improve consumers' visualisation of products, increase engagement, and enhance the shopping experience. Capitalising on these traits enhances retailer and brand perceptions and influences consumer behaviour (Huang & Liao, 2015; McCormick et al., 2014). If designers can create valuable AR experiences, then retailers will buy into AR, helping to revive the high-street through enhanced consumer experiences.

However, designers struggle to apply AR physical retail environments in a meaningful, and lucrative, format (Xue et al., 2018, 2019). While existing AR applications Attract media hype, no retailers—and few consumers—are buying into the technology. The AR development industry, thus, faces a problem: designers' current approach to AR is ineffective. If we can design better AR apps, retailers may adopt the technology for in-store use and increase customer footfall.

This study aims to investigate the consumer value of AR within high-street retailers, evaluate current value (including magic mirror and scanning items), and explore how AR can offer consumers better in-store experiences. To address this aim, we need to know:

1. What value that consumers desire in a physical store environment? This knowledge will help retailers to meet the consumers' increasing, and diversified, demands and enhance competitiveness.
2. What kind of AR app will encourage consumers to engage in physical retail and accordingly, to help the development team understand the developing concept.
3. What is the impact of AR on consumer behaviour and the experience that it delivers? This knowledge will help marketers understand how AR can enhance the in-store experience.

Through two workshops—and AR prototype experience tests—we show retailers can improve the customer experience by designing AR Apps to help shopping's functional (utilitarian) tasks, more than providing enjoyment (hedonic) features; a key feature of e-commerce (Parker & Wang, 2016; Parker & Wenyu, 2019). Participants have a positive attitude towards AR shopping adoption, which will improve consumer satisfaction and boost purchase intention.

2 Methodology

To address the research aim, we undertook our research in three phases: Co-design workshops, prototype generation, and experience prototype experiments.

2.1 Phase One: Co-design Workshops

Phase one evaluated current shopping modes and discovered design opportunities. We used co-design methods by using the touch-point cards and related tools during the customer journey, based on previous literature (Gloppen, 2009; Italian Customer Intelligence, 2015; Lee et al., 2013). As Mitchell et al. (2016) prove, co-design is more likely to create innovative concepts than traditional expert-led ideation methods. The touch-point cards and related tools facilitates mapping, identifying, and analysing results for idea generation in a participatory design workshop.

We targeted 15 participants over three 90–120 min co-design workshops. Our sample comprised utilitarian and hedonic consumers aged 18–34. Previous research shows that 18–34 year-olds are AR's key user base (Mindshare, 2018; Moss, 2019; Parker et al., 2016). Although mainstream high street retailers target 16–45-year-olds, we focus on consumers aged 18–35. 18–35 is the targeted age group of leading high street retailers, for example: Zara 18–40; Topshop 16–30; River Island 18–30; H&M 15–30; and Next 25–35. We used purposive sampling to ensure a suitable spread of participants across each of these categories. We selected qualitative methods because the chosen subject required more in-depth investigation, which will provide multiple contexts for understanding the retail phenomenon under study.

During the workshop, we photographed events with an iPhone X and recorded discussions with a recording pen. We stored all files on a secure server in Loughborough University, under GDPR. We performed the first round of open-coding to capture all emerging themes by reviewing and comparing documentary evidence.

2.2 Phase Two: AR Prototype Design

Phase two used Loughborough University School of Design and Creative Arts's UX flow. We designed two AR prototypes in Adobe XD based on the consumer's pain points revealed from phase one, our primary design persona is a high-street fashion consumer who often shops with limited shopping time.

AR App: https://xd.adobe.com/view/063c9547-baf3-41e2-bfa8-4faafd9439b6-536f/

AR Mirror: https://xd.adobe.com/view/3cecb79d-0cdc-4a06-bf9f-0276137d7cbf-69bf/?fullscreen

Our secondary design persona is a high-street consumer with lacking in fashion sense and enjoys physical interaction with product and people. To compare the differences with established apps, we also built two prototypes of non-AR versions: non-AR App versus AR App and touch screen versus AR Mirror.

2.3 Phase Three: Experience Prototype Experiments

Phase three explored and evaluated the prototypes. We ran experience prototype experiments based in Loughborough University. Each experiment included one participant over 20–45 min.

We ran 42 experience prototype sessions: 11 in AR App, 11 in AR Mirror, 10 in non-AR app, and 10 in non-AR screen. This sample exceeds Nielsen's (2000) minimum requirement for five participants in a usability assessment. Usability is similar to TAM's ease of use, usefulness, and enjoyment components. These experiments targeted consumers aged between 18 and 34, matching Phase One's sample. We used Purposive sampling to ensure a suitable spread of participants across each of these categories.

To prepare for the workshop, we simulated the experience of our concept AR apps by using simple props—including stickers and videos played on an iPad—to role-play the experience of using the AR App and Magic Mirror. We conducted experience prototype sessions in a 'mock-shop' to simulate a high-street fashion shop, see Fig. 1. We asked participants to complete three tasks for each prototype to experience a consumer's entire shopping process—i.e. entering a store, browsing products, selecting products, trying-on and checkout.

Phase three used a mixed-method approach. To quantify the prototype's performance, we measured quantitative task success, task errors, and task time. To quantify satisfaction, we used the SUS Test (Brooke, 1996) with a 5-point semantic differential scales. To qualitatively explore the participant's beliefs, attitude, and intention,

Fig. 1 Experience prototype mock-shop

we asked the participants to complete an online questionnaire: using Kim et al.'s (2017) 7-point Likert scale descriptors and 7-point semantic differential scales.

2.4 Data Analysis

For statistical analysis, we conducted between groups comparisons through Mann–Whitney U Tests as each group's sample sizes are small (n = 22) and Likert scales break parametric statistics' assumption of normality.

To understand the participants' experience, we asked participants to 'think aloud' their prototype interactions—verbalise their actions and thoughts—while being videoed. Post-interaction interviews explored their reaction and behaviour through semi-structured interviews. We transcribed, documented, and coded the tests using NVivo 12 (QSR, 2019). Using NVivo for thematic analysis, we achieved a more in-depth insight into the data than otherwise possible. Through thematic analysis, we understood participants consumer's reactions to AR concept apps, their value perceptions, and the experience of AR concept apps. By comparing different AR (and non-AR) prototypes, we determined the most promising form of AR for high-street fashion retail.

3 Results

Phase one's workshops converged on three pain points of physical retail: queueing for changing and paying, wasting time trying-on unsuitable items, and limited product information. Phase two's designs aimed to bring an innovative consumption pattern and shopping mode, to help consumers to save time and efforts, provide useful information, and offer a seamless shopping process.

In phase three, we cross-compared the four prototypes. Figure 2 presents the means

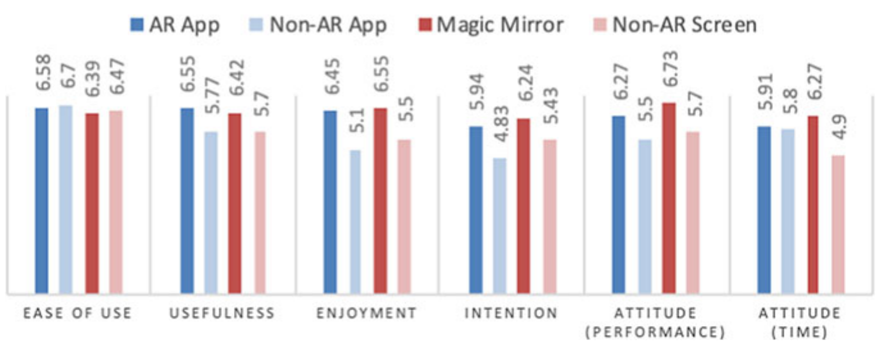

Fig. 2 Comparison between the means of AR prototypes and non-AR prototypes

Table 1 Compare significant level of Mann–Whitney U test between prototypes

Prototype	Ease of use	Usefulness	Enjoyment	Intention	Attitude-performance	Attitude-time
AR app versus Non-AR apps	P = 0.31	P = 0.28	**P = 0.03**	**P = 0.04**	P = 0.43	P = 1.00
AR mirror versus Non-AR screen	P = 0.51	P = 0.31	**P = 0.01**	P = 0.11	P = 0.28	P = 0.09

of four prototypes in different variables, the mean reflects the average response of one prototype, we can use it to compare different sets of data to see the differences between prototypes. The higher score leads to a more favourable result.

Table 1 compared the Man-Whitney U test' significant levels for the four prototype groups. We used the standard significance level of $\alpha = 0.05$. The result highlights that the enjoyment of both AR prototypes and intention of AR App have significant differences when comparing to non-AR prototypes.

3.1 AR App Versus Non-AR App (Quantitative)

Participants showed enthusiastic responses towards the AR Branded App compared to non-AR Branded App. The participants perceived that the AR app is straightforward to use, although the score is less than the non-AR App. The AR App should provide more utility than the non-AR App. There is a significant difference in enjoyment and intention between AR (M = 6.45) and non-AR app (M = 5.1). Most participants found that the design and application of AR is fascinating and enjoyable. Because the workshop is a simulation scenario, the participants need to imagine without any prior use or experience of the technology. The non-AR version is, therefore, more like an existing app consumer are using every day without any flashpoint.

3.2 Magic Mirror Versus Non-AR Screen (Quantitative)

All the scores of measurement items in AR Mirror are similarly inflated compared to non-AR screen. Figure 2 shows participants perceived ease-of-use of AR Magic Mirror (M = 6.39) equals the Non-AR touch screen (M = 6.47). The similarity in ease-of-use means participants can accept or learn to use the new function easily since both prototypes provide fundamental features, enabling participants to quickly understand the prototype without the further help of technical assistants. Participants regard AR Magic Mirror as advantageous. They were happy to explore the AR Magic Mirror because it has some futuristic elements which they experience for the first time. Participants were also curious to explore the AR Magic Mirror. Non-AR touch screens, by contrast, are considered as an existing app that may not draw much attention when the smartphone is the ubiquitous tool? at the moment.

3.3 AR App Versus Magic Mirror (Qualitative)

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

3.4 Beliefs (Ease of Use, Usefulness, Enjoyment)

Participants enjoyed exploring the AR prototypes because they were curious to play with futuristic elements which they have not experienced before. No participants thought entertainment would trigger their intention to use the AR App or AR Mirror. Entertainment's indifference is critical as enjoyment was the only significant differentiator between AR and Non-AR prototypes. AR's main strength may not increase the consumer's willingness to use the—expensive—technology. Seductive, evocative, and desirable design is, therefore necessary despite being insignificant to differentiate between AR and Non-AR Apps. Consumers may enjoy being in the store, but if the app did not give them what they want, they would leave the store. Developing high-tech elements to work with a customer's existing shopping patterns will provide more utility to high-street retail; such as product interactivity, AR/VR elements, and Artificial Intelligence (AI) assistant. In this way, the shopping activities will become smarter and more enjoyable at the same time.

3.4.1 Intention of Purchasing and Visiting

The study discovered many pain-points toward the branded app prototype. In order to filter the most suitable products for consumers, the app has designed many filter conditions for participants. 36% of the participants, however, stated that there are too many steps to fill in. Designers should create the app to be as simple as possible to reduce consumer effort. Another barrier is the app is unable to measure the accurate size for consumers. Three participants indicated they were still unsure about the size without trying. 81% of participants said they are more likely to visit an apparel shop that provides this AR app because the AR brings the online shopping advantage to in-store shopping. The AR app also brings a novelty effect generated by this innovative experience. The participants, however, have low trust of AR try-on through Magic Mirror. Physical stores will invest heavily in this technology, money and time

Table 2 Relevance characteristics of AR branded app and magic mirror in interview—coding reference

Theme	Category	Themes from Data	Branded App	Magic Mirror
Beliefs		Ease of use	2	5
		Enjoyment	0	0
		Usefulness	9	6
Attitude	Positive	Convenience	3	3
		Entertainment	2	7
		Helpful and useful	6	7
		New way shopping	5	9
		Save time and efforts	3	3
	Negative	Prefer human service	1	0
		Do not Trust the effect	0	1
Adoption Intention	Influential factors	AR effect vs real	3	4
		Availability of sales assistant	3	1
		Ease of use	7	5
		Interface design	3	2
		Knowledge of AR	0	1
		Comfortable to use	0	1
		No. of belonging	1	4
		No. of items to try-on	0	3
		Available shopping time	2	2
		Low response	4	4
		Need of use (function)	20	10
		Update information	5	2
		Popularisation	4	3
		Quality of information	2	2
		Queue and crowd	4	8
		Shop alone	2	0
		Store tidiness	2	1
	Pain-point	Inaccurate to direct/ simulate	2	3
		Limited function	1	0
		Privacy concern	1	4
		Too complex	4	4
		Shop without trying	3	3
		Crowd and queue	0	2
Purchase intention	Positive	Browse all product range	3	4
		Matching	7	8
		Better understand of a product	2	1
		Navigation	4	N/A
		Product filter	4	N/A
		Entertainment	0	4
	Negative	Unnecessary	1	1
Visit Intention	Positive	Combine online shopping	3	0
		Find product quicker	5	0
		Inspiration	2	3
		Novelty effect	2	8
		Fun and interesting	0	2
		Try-on	N/A	4
	Negative	Not as convenient as online	2	3
		Not enough attractive	1	0
Satisfaction	Positive	Convenient	22	13
		Fun and interesting	3	6
		More information	14	8
		Smart shopping	6	9

(input product). Researchers and retailers can hence, understand that participants may be negative about AR's performance in physical stores at this stage. Nevertheless, participants intend to use the Magic Mirror largely because of the novelty effect of this new in-store technology rather than its practicality.

3.4.2 Attitude and Satisfaction

Through a 'think aloud' process, participants felt like they were playing a mobile game. In this 'game-like' environment, the physical shopping activity is closer to the digital world. However, AR apps and Magic Mirrors also offer greater convenience (self-checkout, self-shopping, and navigation) and useful information (product information, style inspiration, and stock availability). Only one participant reacted negatively with the app, because they prefer human service sometimes in the store instead of a self-service app. In this case, we suggest integrating AI—or live human assistants—into the app to help consumers address the real-time issue. The attitude toward Magic Mirror is more positive than the branded app. All participants indicated they are looking forward to experiencing the Magic Mirror in the store. There is a higher probability that consumers will spend more because of the convenience and as more options become visible unwanted products are back on the consumer's radar.

4 Discussion

4.1 AR Versus Non-AR Versions

Participants showed enthusiastic responses toward the AR version compared to the non-AR version. The participants are familiar with the non-AR version, which is similar to the existing shopping apps they use every day. While our results show that participants can accept, or learn to use, the new AR function very easily. Fashion consumers should be able to adapt to the AR version over time. Both the AR and non-AR prototypes can achieve the same outcome but differ in AR technology. The features in the prototypes will help consumers in their shopping experience where participants perceived usefulness of AR prototypes is 1 score higher than non-AR prototypes.

The Mann–Whitney U Test shows a significant difference between 'AR prototype enjoyment' and 'the intention to use AR Apps'; when comparing to non-AR prototypes. This means participants enjoy exploring the AR prototypes the most since they were curious to play with futuristic elements for the first time. Hence, AR technology can be the value in entertainment or experience that enriches the shopping process, making the physical shopping more interesting. No participants, however, thought entertainment would trigger their intention to use the AR App or

AR Mirror. Entertainment's indifference is critical as enjoyment was the only significant differentiator between AR and Non-AR prototypes. AR's main strength may not increase the consumer's willingness to use the—expensive—technology. Seductive, evocative, and desirable design is, therefore, necessary despite being insignificant to differentiate between AR and Non-AR Apps.

4.2 AR APP Versus Magic Mirror

Of the three TAM variables, perceived usefulness is the most important factor for participants to use the AR branded App. The participants perceived ease of use will, however, influence their intention to use the Magic Mirror. These results, however, indicate that the physical and online retailers have different affected factors towards attitude on AR, as shown in the findings from previous studies (Childers et al., 2001; Lee et al., 2006) where perceived enjoyment had the strongest effect on attitude. Perceived enjoyment did not produce a significant direct effect on behavioural intentions toward the online retailer. However, there was a significant indirect effect of perceived enjoyment on behavioural intention mediated by attitude toward the physical retailer. We therefore recommend the apps should be user-friendly to all consumers, keeping functions clear and concise, avoiding garish or over-complicated details—in line with Nielsen's Heuristics for UI design (Nielsen, 1994).

Our prototypes offer convenience for utilitarian consumers who want to save time and effort, and approach a specific product. Increased utilitarian functions align with the research of Olsson et al. (2013) and Spreer and Kallweit (2014). As the use's benefit plays an important role for the usage intention, functional, and solution-oriented applications are rated more positively than enjoyment-oriented ones. The AR apps will not, however, save time for consumers who want to spend time in the store (adventure shopping and gratification shopping). These consumers, for example, plan to shop for certain hours, with or without AR. Consumers' shopping efficiency and purchase intention will be improved since AR can help them make decisions quicker.

Participants are more likely to use an AR branded app rather than a Magic Mirror. This is because most consumers have their own devices to access app stores, unlike the Magic Mirror, which has a limited number in the shop-floor. The consumer may also feel uncomfortable to use the mirror when other consumers are waiting for them. Although the Magic Mirror is enjoyable and useful but raises new concern of queuing, which need to be taken into account when applied in the store. Meanwhile, some participants are still relying on trying by themselves. As a Magic Mirror cannot completely replace a fitting room—but can reduce fitting room queuing- so that the main purpose of fitting rooms for consumers is to check if the size fits them.

4.3 Enjoyment

Consumers may enjoy being in the store more than online shopping, but if the app did not give them what they want, they would leave the store. Developing high-tech elements to work with a customer's existing shopping patterns will provide more utility to high-street retail such as product interactivity, AR/VR elements, and Artificial Intelligence (AI) assistant. In this way, the shopping activities will become smarter and more enjoyable at the same time. This is especially true for Magic Mirrors that involve interactive elements to offer consumers a more enjoyable shopping experience. When the consumer picks up an item and tries it on virtually, projecting the item onto oneself is more enjoyable than projecting it onto a model. Enjoying the shopping processes more will enhance consumers' engagement to see how the item looks on them and improves satisfaction. Interactivity entertains users and enables them to personalize information in a 3D virtual model (Fiore et al., 2005). Consumers enjoy interacting with virtual objects more than they do handling or looking at physical objects (Li et al., 2001).

The smart shopping process enables consumers to feel good and enjoy the shopping activities more than compared to current shopping mode. Furthermore, increased emotional experiences will lead to consumers spending more time on shopping, increasing brand likeability and shopping more often than before. Regarding the retail industry, the use of AR provides an opportunity to close the information gap at the point of sale and have a positive impact on customer satisfaction.

4.4 Intention

Participants are looking forward to experiencing the AR function, desiring something new to change their traditional instore shopping style. Participants, however, lack confidence in the outcome/performance that AR can offer now, which will prevent consumers from using it. AR try-on, for example, may not accurately simulate the product's size, prohibiting consumers from comparing two garments fully. Consequently, consumers must spend time to trying-on garments—as they currently do in-store. Furthermore, the shop's displays must be orderly so the app can identify specific items accurately. Store employees must, therefore, spend more time organising the store—a significant investment in labour. Shoes, for example, have their own characteristic, which demands big data and requires many details to present.

Table 3 Design solutions for in-store AR retail

Design aim	AR solutions	Impact
Offering convenience	Consumer can log in to their account. The account will save the their preference. According to the personal data, the app will suggest the size for consumers	• Enhance consumer loyalty • Keep existing consumer group
Improving accessibility	Keep the procedure simple, and avoid unnecessary steps and features	• Reduce acceptance barriers • Appeal new consumers
Up-to-date information	Show and update the number of items in stock, to avoid consumers reaching the store with an out of stock situation	• Increase consumer satisfaction
	Frequently update the navigation under store merchandising direction	• Increase consumer satisfaction
Improve modelling accuracy	Showing size differences when virtual trying-on	• Increase purchasing intention • Increase stakeholder value
Improve the content richness	Offering 'Buy for others' option enables consumers to select the most suitable item for others by uploading the photo	• Increase enjoyment level • Increase overall profit
Keep seamless shopping experience	AR functions should be consistent with the supporting facilities in the store	• Increase consumer base • Encourage consumer motivation
	Integrate with other high-tech equipment Self-check-out to reduce the queue and save time AI assistant to answer the question for consumers	• Increase consumer satisfaction

5 Conclusion

To enhance the in-store shopping experience, we should design AR apps to follow the factors in Table 3.Our results suggest that through these advanced AR experiences will encourage fashion-based business improvements.

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The Role of Mental Imagery as Driver to Purchase Intentions in a Virtual Supermarket

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Abstract This study aims to explore the role of mental imagery, product involvement and presence on emotions and purchase intentions. A quasi-experimental between-subjects design was implemented to test the proposed model. The quasi-experimental manipulation comprised a virtual grocery store, using VR. A quantitative approach was followed using a questionnaire to get data to test the model. The questionnaire was fulfilled after the 108 participants visualize the scenario through VR. The results reveal that all hypotheses are supported, expect H4. Product involvement is not associated to emotions.

Keywords Mental imagery · Product involvement · Presence · Virtual supermarket · Purchase intentions

1 Introduction

The new Marketing era became a huge challenge for retailers. The field of retailing suffered a lot of changes mainly due to technologies. Consequently, consumer behaviour is also different from past years (Grewal et al., 2017; Pizzi et al., 2019). Nowadays, consumers are more demanding and became more complex. Technologies are not the only driver of this change. According to Shankar et al. (2011), there are other three important drivers: economy, regulation, and globalization. On this research we will focus only on technology.

Retailing is shifting from traditional marketing to a modern in-store practises where the omnichannel is the key (Deng et al., 2019; Souidena & Ladharia, 2018).

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Thus, reaching this omnichannel model involves the use of multi-channels and, additionally, the increase of shopper touchpoints (Shankar et al., 2011). This multichannel environment is enhanced by some new technology development such as advanced mobile devices and interfaces, powerful search engines, online social networking (Shankar et al., 2011), physical in-store locations, mobile web (Souidena & Ladharia, 2018) and also virtual and augmented reality (Grewal et al., 2017). Slowly, retailers are trying to establish contact with their clients by converging offline and online channels.

The purpose behind this change is how it will impact consumer behaviour and their shopping experience. The use of these innovations intends to help customers make a good purchase decision, feel less time pressure, increase their satisfaction and pleasure, feel more engaged and make efficient and quick purchases (Grewal et al., 2017). Although this new experience approach brings a big opportunity for brands, it is also a field that is difficult to develop and needs a lot of study in the years ahead.

Virtual Reality (VR) has offered a large potential for a long time, but those opportunities are just beginning to come true, not only by the hands of retailers but also by the ones of shoppers. Though marketing experts see the evolution of VR with high hopes for companies, there are no clear guidelines as to how they should integrate it on their marketing mix (Tom Dieck et al., 2018). So, more research is needed to understand the potential of this tool. Virtual Reality is based on three key characteristics: immersion, interactivity mix (Tom Dieck et al., 2018). Firstly, when exposed to a virtual environment, the individual experiences the sense of immersion or presence within that environment. The user feels like being there and escaping or becoming isolated from the real world. Beside immersion, VR provides a very dynamic environment (Loureiro et al., 2019), which is important to create consumer involvement. Hence, the current study explores mental imagery as driver to emotions and purchase intentions in virtual supermarket.

2 Theoretical Background

2.1 Virtual Reality

In response to these new trends, companies have developed strategies to be relevant to customers and competitive in the market. Smart technology can enhance the quality of a shopping experience (Berg & Vance, 2017; Kerrebroeck et al., 2017). One of those key transformations uses VR.

VR has offered a large potential for a long time, but those opportunities are just beginning to come true, not only by the hands of retailers but also by the ones of shoppers. The new form of technology based on reality is a way to enhance sensory perceptions, if well used (Grewal et al., 2017). Though marketing experts see the evolution of VR with high hopes for companies, there are no clear guidelines as to how they should integrate it on their marketing mix (Boyd & Koles, 2018).

The term "Virtual Reality" began early with the visionary Sutherland (1970), who believes VR is a model of real world in real-time, in which the user feels like it as a reality they can manipulate directly and realistically. After that, various authors came up with different definitions, complementing each other. However, a few years later, Steuer (1992) gave us a more scientific approach, defining Virtual Reality as a stimulated environment in which the individual experiences telepresence, that is, the person feels present in a virtual world. In VR, the user emerges in a computer-generated environment where it is possible to perceive, act and interact with a three-dimensional world (Borawskaa et al., 2018). Kerrebroeck et al. (2017) also contributed to this concept, referring to it as computer-based technology that engage with the human senses (vision, hearing, among others …) and consequently create the feeling of being there. Summing up, VR is a three-dimensional world with realistic sensations, which can stimulate a physical presence of environments that exist (Farshid et al., 2018).

VR is based on three key characteristics: immersion, interactivity (Boyd & Koles, 2018; Kerrebroeck et al., 2017; Meißner et al., 2017) and the ability to create real-time engagement (Boyd & Koles, 2018). Firstly, when exposed to a virtual environment, the individual experiences the sense of immersion or presence within that environment (Loomis & Blascovich, 1999). In other words, the user feels like being there and escaping or becoming isolated from the real world (Kerrebroeck et al., 2017). Beside immersion, VR provides a very dynamic environment (Boyd & Koles, 2018), which is important to create consumer involvement. According to Steuer (1992), the user can participate by modifying form and content of the environment in real time.

2.2 *Virtual Reality as Marketing Tool*

At first, VR was being used in areas like gaming and entertainment, but the tool quickly extended to other areas, such as education and tourism (Marasco et al., 2018). Eventually, it was also used in marketing. Professionals realised its impact in consumer engagement and especially in their shopping experience. As a result, companies have used that to make the purchase more entertaining and convenient. For example, one of the biggest retailers in the UK, Tesco, is testing the opportunity of having a virtual retailing environment (Meißner et al., 2017). The company believes that with this technology they can change consumer behaviour (Lemon & Verhoef, 2016).

Looking at the impact of VR in shopping experience more closely, retail atmosphere is changing to digital solutions which enhance the stimulus at the point of sales much more (Kerrebroeck et al., 2017). A study made by Marasco et al. (2018) concluded that by having a Virtual Reality Experience before choosing a country destination, users had a positive and noteworthy influence on their behavioural intentions.

Specifically, a Virtual Reality experience combines multiple sensory channels (Borawskaa et al., 2018), which leads to high engagement with shoppers and therefore has a positive impact on attitudes and approach behaviour (Kerrebroeck et al., 2017). Thus, it is possible to name specific benefits from this technology to influence consumer behaviour. This is the feeling of being there, creating value by having an enjoyable experience, inducing positive emotions, impacting brand perception, influencing purchase intention, and enhancing brand experience. Before that, Sands et al. (2015) have already concluded that there is a direct link between positive emotions and shopper behaviour. In fact, when the experience incites a positive emotion, people tend to stay longer inside the store, which generates more sales and increases the intention of returning.

3 Hypotheses Development

3.1 Purchase Intention

The purchasing process can be influenced by several factors. Marketing researchers need to study and identify those specific factors. To begin with, it is necessary to clarify the meaning of purchase intention. "Purchase intention is a kind of decision-making that studies the reason to buy a particular brand by consumer" (Mirabi et al., 2015, p. 268). Hsiao and Chen (2018) defined the concept as the likelihood of a customer to purchase a specific product, after evaluation (Younus et al., 2015). The definition seems to be simple. However, the process of customer decision is very complex and usually depends on the behavior, perceptions and attitudes of consumers. Moreover, before the final purchase intention, the customer goes through six strages: awareness, knowledge, interest, preference, persuasion and finally purchase (Mirabi et al., 2015).

Purchase intention is affected by several factors (Younus et al., 2015). *For example, one can find a positive correlation between purchase intention and factors such customer knowledge, celebrity endorsement, product packaging and perceived value. Price has a huge impact on the final purchase decision* (Lee et al., 2017). *Customer attitude through product branding is also particularly important* (Hsiao & Chen, 2018)*, because if the individual has a positive attitude, there is a higher probably that they will buy.*

To sum up, marketers need a clear strategy to understand the reasons that lead the customer to buy a specific product and leverage the purchase intention and VR become a potential effective marketing tool for that. A study conducted by Suh and Lee (2005) concluded that using VR can influence the purchase intention.

3.2 Emotional States

Consumers have different experiences by consuming products and those experiences elicit many emotions. Those emotions can, in turn, influence the overall satisfaction and the opinion of the consumer. One of the most common and oldest definitions of emotion come from Mehrabian and Russel (1973), who state emotions are a multi-component phenomenon with multi-component responses, including a set of behavioral and physiological reactions and subjective feelings, that is, the reactions an individual has to a given stimulus. Emotions are stimulated by specific situations, and that occurs instantaneously (Belverde & Goodwin, 2017). When it comes to the marketing field, marketers believe that a product or an experience elicit emotional reactions, which they call consumption emotions (Porral et al., 2018; Ferrarini et al., 2010).

Emotional reactions refer to positive or negative feelings toward a product (Belverde & Goodwin, 2017; Bakker et al., 2014; Cowan & Ketron, 2019) *and consequently the pleasantness or unpleasantness during the experience* (Porral et al., 2018). *These emotional reactions result in liking or disliking, and this is how the consumer creates his own judgement* (Belverde & Goodwin, 2017). *Moreover, emotions not only represent the reaction of a specific experience, but also the assessment and evaluation of that moment* (Porral et al., 2018).

Hence, we experience a range of emotions through different media. Hereupon, emotions are a key driver to engage with the different experiences we are exposed to (Mullins & Sabherwal, 2018). On the other hand, cognition refers to the way the mental activity acquires and processes the knowledge obtained during the experience (Anderson, 2000) through attention and memory (Mullins & Sabherwal, 2018). These two components can influence decision making.

3.3 Mental Imagery

Mental imagery has been studied by many researchers. In neuropsychology this is defined as "quasi-perceptual experience manifested in the form of sensory, picture-like representations in the human mind, generated in the absence of true stimuli" (Bogicevic et al., 2019, p. 56). According to Miller et al. (2000), it is an activation of perceptual knowledge stored in a long-term memory and related to a personal experience. With these characteristics, marketers believe that mental imagery can be a stimulus for consumers. Indeed, the presence in an imagined situation can bring various outcomes between the consumer and the brand, such as attention, memory, positive feelings, or behavioural responses (i.e., purchase intention) (Ha et al., 2019). Because of that, this matter has gained extreme importance in literature.

Mental imagery can be evoked in different ways. Babin et al. (1992) *were one of the first to study this topic. According to them, there are three traditional ways to evoke mental imagery: pictures, concrete words, and instructions. It is believed pictures* *have a superior impact on mental imagery* (Ha et al., 2019). *Many scientists proved that visual information is easier to remember than the verbal dimension. On the other hand, concrete words are a way for people to easily create the imagery on their mind. That is why the use of concrete words in advertising is so important* (Babin et al., 1992). *Finally, when a person receives specific instructions to imagine, the mental imagery is stimulated. Even though those are the main factors found by research to stimulate mental imagery, nowadays there are new types and more technological ways to help. For example, three-dimensional images and virtual reality* (Bogicevic et al., 2019*), digital games or mobile ads* (Ha et al., 2019).

Regarding the dimensions that characterise mental imagery, it is defined as a multidimensional process. Through the years, various theories appeared with new types of dimensions. However, it is now possible to conceptualise the process like this (Miller et al., 2000)*: quantity, vividness, valence, and modality.*

Firstly, quantity or elaboration (Bogicevic et al., 2019) *relates the number of images formed on someone's mind and memory activation, when exposed to an image* (Yoo & Kim, 2014). *Vividness is concerning to the quality of images generated and how intense they are in one's mind* (Miller et al., 2000)*, which means clarity, vibrance and distinctiveness. These dimensions are believed by many authors to be the main drivers of Mental Imagery* (Ha et al., 2019). *However, effective tone has a huge influence too, since it reflects the emotional meaning of the recall memory and provokes the individual's emotional reaction* (Yoo & Kim, 2014). *Imagery can be evoked by different types of sensory stimulus: tactile, visual, auditory, olfactory, or gustatory. This dimension is called modality* (Miller et al., 2000).

Analysing the mental imagery characteristics, one can find a relationship between mental imagery and consumer behavioural intentions (Yoo & Kim, 2014). *The imagery environment provokes positive emotions during the shopping experience because these stimuli affect the cognitive, affective, and emotional responses to marketing messages* (Miller et al., 2000).

Following Miller et al. (2000), mental imagery is an activation of perceptual knowledge stored in a long-term memory and related to a personal experience. *Imagery can be evoked by different types of sensory stimulus: tactile, visual, auditory, olfactory, or gustatory. This dimension is called modality* (Miller et al., 2000). *Thus, mental imagery is associated to consumer behavioural intentions* (Yoo & Kim, 2014)*, that is emotional states and purchase intentions. Therefore, the following hypotheses are formulated:*

H1*: Mental imagery is positively associated to Purchase Intention*
H2*: Mental imagery is positively associated to Emotions.*

3.4 Product Involvement and Presence

Few studies have been made regarding the impact of product involvement in consumer experience. However, some authors have developed definitions for this concept. One *of the pioneers on this matter was* Zaichkowsky (1984, p. 342)*who defined Product Involvement as* "A person's perceived relevance of the object based on inherent needs, values, and interests". *In other words, this means that product can play an important and different role for each consumer* (Porral et al., 2018). *Indeed, product involvement reflects the amount of interest, attention, excitement, and motivation of the consumer toward a product* (Porral et al., 2018). *The involvement differs from consumer to consumer, depending on personal factors, choices, and product significance* (Peng et al., 2019). Very briefly, product involvement has to do with the customer perceived value (Peng et al., 2019).

The level of involvement differs from product to product in a scale of low to high involvemtent. The degree varies depending on the effort that consumers put into getting the product, the time invested in the decision-making process, the financial and social risk of the purchase (Porral et al., 2018) and the engagement experience itself (Cowan & Ketron, 2019). The level of consumer involvement influences the importance that the person gives to the product, the amount of information search (Porral et al., 2018) and the decision behaviour (Peng et al., 2019). When it comes to products with high level of involvement, consumer attention is stronger (Belverde & Goodwin, 2017), so they show greater interest in searching information about the product (Cowan & Ketron, 2019) and comparing the attributes from different products in the same category (Porral et al., 2018). Consumers are willing to invest time in making a decision, becoming a more complex process. Actually, with a high involvement, customers tend to make decisions based mainly on cognitive attributes, which means that a particular consumer depends on more rational judgments (Peng et al., 2019) in order to avoid risk. When a person is highly involved with a product, the expectation of value increases and he becomes more sensitive to price.

Hence, product involvement reflects the amount of interest, attention, excitement, and motivation of the consumer toward a product (Porral et al., 2018).

So, it is important to understand how to communicate with products with different levels of involvement, because it influences the way customers want to engage with the brands (Porral et al., 2018). *Based on this assumption, it is expected that:*

H3*: Product involvement is positively associated to Purchase Intention*
H4*: Product involvement is positively associated to Emotions.*

The feeling of presence brought out by the virtual reality stimulus usually creates a highly involvement with the store atmosphere (Boyd & Koles, 2018). *People can experience the feeling of escaping and telepresence without moving* (Kerrebroeck et al., 2017) *and influence their behaviour. Based on this the following hypothesis arise:*

H5*: Presence is positively associated to Purchase intention*
H6*: Presence is positively associated to Emotions.*

4 Methodology

A quasi-experimental between-subjects design was implemented to test the proposed model. The quasi-experimental manipulation comprised a virtual grocery store, using VR. A quantitative approach was followed using a questionnaire to get data to test the model. The questionnaire was fulfilled after the 108 participants visualize the scenario through VR using Oculus Rift. The Laptop specification is MSI GT62VR Intel(R) Core(TM) i7-7700HQ CPU @ 2.80 GHz Memory RAM 16.0 GB Graphics GeForce GTX 1070.

The respondents are regular shoppers who were selected to test a virtual shopping. A virtual scenario was created where the participant experienced a virtual supermarket. The scenario displayed the product assortment, prices, and promotions. Participants were requested to wear Oculus Rift, which includes an appropriate oculus to emerge in a virtual world and two motion sensors that detect the movement. Besides, a computer with the software to design the virtual scenario was used. The virtual supermarket was based on an existing shelf layout and real brands to resemble the physical experience. The laundry care category was chosen, specifically, HDD—Hard Duty Detergent—and FFI—Fabric Finishers. It is important to refer that to ensure maximum fidelity and allow participants to do the correct comparison, the virtual planogram was based on an existing shelf layout and real brands (Pizzi et al., 2019). Furthermore, the point of sales environment was reproduced, such as shelves, floor, and lighting.

5 Results

PLS (the partial least squares) approach is used to test the model. PLS is suitable for this study since it is used for constructs under condition of nonnormality and for small-medium sample sizes. The analysis was conducted on two levels: the first-order constructs level and second-order construct level. The latter correspond to mental imagery with four factors: vividness, quantity, valence, and modality. After analysing the measurement model, convergent and discriminant validity, the structured model is appraisal. Concerning the established hypotheses, at a significant level $p < 0.05$ ($t > 1.96$), hypothesis H1, H2, H3, H5 and H6 are fully supported, only H4 is excluded.

6 Conclusions and Implications

The results show that mental imagery leads to a purchase intention ($\beta = 0.307$), the positive relationship means that, when in the shopping experiences, and images are evoked to our mind, we tend to be more propitious to buy the product. Thus, mental imagery explains the purchase intention variable and H1 is supported. Concerning the emotions, the results show that there is a relationship between both (β = 0.611), which means that, when in the shopping experiences and images are evoked to our mind, the emotional reactions to the stimulus are positive and agreeable. Thus, mental imagery explains the emotions variable and H2 is supported. It is crucial to highlight that the positive effect of mental imagery in emotion is the strongest direct effect of whole hypotheses, pointing out the crucial role that mental imagery may play in the emotions generated. This result is already expected, having in mind the findings in literature review. Emotional responses occur when our cognitive sense is stimulated (Miller et al., 2000) and according mental imagery definition, this is exactly what happens when the mental images come to our mind.

Although each consumer has a different level of involvement depending on the product we are talking about, product involvement is not the same for all consumers. The level of involvement will determinate the consumer attitude towards the product. Researchers consider that brands should approach differently the audience according the level of involvement. This is where VR has an important role.

The results show that product involvement leads to a purchase decision (β = 0.203), the positive relationship means that, when in the shopping experiences, and consumer who is highly involved with the product/brand, tends to be more propitious to buy the product. Thus, product involvement explains the purchase intention variable and H3 is supported. It can be explained due to the category chosen for this study—laundry care. This type of category includes products with high involvement level. Consumers of this category mostly look for the maximum information possible, such as benefits, prices, environmental issues, among others … and tend to compare between the different brands which is the best option that will fulfil their needs. The variable product involvement presents a mean of 4.54, meaning that even not totally involved, the sample shows a positive level.

The positive or negative emotions stimulated depend product involvement (Porral et al., 2018). On one hand high involvement leads to a positive and pleasurant emotions, on the other hand low involvement leads to a negative emotions. This is justified by the fact that people feel more linked with products that elicit to a pleasure emotions rather than unpleasent emotions. Thus, hedonic value of the product also influences the involvement and the emotions triggered, since in hedonic value people look for pleasurant experiences. In Porral et al. (2018) case the products involved are wine (high involvement) and coffee (low involvement).

Regarding presence, this leads to a purchase decision (β = 0.491), the positive relationship means that, when the consumers feels physical present in a virtual world, tends to be more propitious to buy the product. Thus, presence explains the purchase intention variable and H5 is supported. Concerning to the impact of presence on emotions, as expected, the relationship is significant and positive (β = 0.191). This means that the interactivity and immersion experienced on virtual supermarket enhances the emotions generated. Therefore, presence explains the emotion variable and H5 is supported. It is crucial to highlight that the positive effect of presence in emotion was the weakness direct effect of whole model, in other words the role that presence may play in the emotions is not the most important in the whole model.

The present study and respective empirical analysis bring a meaningful conclusion which can have impact on marketing field. The findings highlight the importance of the atmospheric conditions for the overall shopping experience in a specific market. More precisely, the impact of a virtual environment in all customer journey, until the purchase decision.

Therefore, managers should study deeply the market where they are inserted and above all the type of consumer and their shopping behaviour to create a greater experience with a virtual store. Creating the appropriated atmosphere, where the consumer feels immersive and part of the process is a key driver to his satisfaction and increase the purchase intention. And as the study showed, virtual reality as a good effect on it.

For customers, going to a virtual store needs to be a differencing experience, comparing with a physical and common store. The results showed that when the consumer perceive the virtual shop as similar to a physical one, the purchase intention decreases, and emotions are not generated. So, people need to perceive that they are in a virtual and immersive world. This leads us to another important conclusion, the feeling of presence. In fact, raising the effect of presence in another world seems to be a great factor to create positives emotions and consumers' responses.

To sum up, this study comes to emphasize the importance of creating the right atmosphere for a better shopping experience. Marketers must provide a personalized shopping experience given that the different variables that influence the shopper's behaviour.

VR still be a very new tool that people are not used, and it must be applied in marketing step by step. On the one hand, consumers need to be educated for this new shift from traditional to innovative marketing. On the other hand, companies need to take the best part of it and surely create the best atmosphere condition to lead positive emotions and finalizing with a purchase decision. How more involved is the consumer with the product, the more he needs to be engaged with the brand. So, creating the appropriated atmosphere, where the consumer feels immersive and part of the process is a key driver to his satisfaction and increase the purchase intention, and as demonstrated here, VR is a good effect on it.

Despite the contribute of this study, the results and conclusions should be interpreted according with some specific limitations. The main constraint of the method regards to the data collection. Firstly, the sampled used is not representative since 108 participants are not enough to understand behaviours. Besides few men were able to participate because it is not easy find men that are used to shop laundry products or know the category. A more extensive and diversified sample could lead to different results. For future research, a larger sample must be considered.

In addition, it would be interesting to consider doing the experience with participants right after leaving a physical supermarket and compare both shopping experiences. Actually, the experiment process makes it difficult to access to more participants and the time of collecting data was longer and delayed.

Another limitation on this study is the use of the virtual reality program to create the scenario. In the future different scenarios should be interesting to analyse and understand if the relationship between variables change or not. To complement the model, other variables should be integrated, such as satisfaction or recommendation.

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User Responses Towards Augmented Reality Face Filters: Implications for Social Media and Brands

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Abstract Augmented reality (AR) is increasingly shaping brand-customer touchpoints. On social media, brands are developing AR face filters to engage consumers. This study analyses the use of AR filters in users' experiences. Data from social media users of AR filters was gathered using an online questionnaire. Results showed that branded AR filters generated higher perceived originality, aesthetic quality and interactivity than non-branded filters. For branded AR filters, usefulness (determined mainly by interactivity) fostered behavioural intentions towards brands; while enjoyment (determined mainly by aesthetic quality) enhanced behavioural intentions towards social networks. The results offer interesting implications for brand managers and AR filters developers.

Keywords Augmented reality · Face filters · Social media · Branding · Enjoyment · Usefulness

1 Introduction

The ubiquity of the smartphone and its integrated camera is changing the marketing communications' landscape (Kim & Lee, 2018). The development of Augmented Reality (AR), which superimposes digital content on the users' real surroundings (Azuma, 1997; Flavián et al., 2019a), is generating a new physical-virtual reality where consumers, products and companies interact in unprecedented ways (Javornik, 2016). This technology is expected to shape brand-customer interactions, as AR allows companies to fuse and entangle branded contents with customers' environments and bodies (Scholz & Duffy, 2018). For example, AR can be used to assist

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consumers' navigation and wayfinding (Bona et al., 2018), to pre-experience products before buying them (Fan et al., 2020), and to improve the in-store experience (e.g., Toys R Us Play Chaser app; bit.ly/2Sjqoal [https://www.theverge.com/2017/10/3/16408448/toys-r-us-ar-app-play-chaser]). Importantly, companies are using AR in their advertising campaigns (e.g., Burger King's Burn that Ad; bit.ly/37fQpeZ [https://adage.com/creativity/work/burger-king-burn-ad/1662576]) and printed catalogues (e.g., Mothercare; bit.ly/2SD13an [https://etaileurope.wbresearch.com/mothercare-augmented-reality-mobile-retail-strategy-ty-u]) that allow consumers to have a more interactive and entertaining experience than with traditional formats. In fact, the AR market size worldwide is estimated to increase from USD3.5 billion in 2017 to more than USD198 billion in 2025 (Statista, 2020a). All these data illustrate the potential of AR for marketing communications.

Social media is also taking advantage of this optimistic outlook. Recently, Appel et al. (2020) stressed the rise of social networking sites (SNSs henceforth) as the main platforms for marketing communication activities, and identified AR as one emerging trend that will determine the development of SNSs. In this way, AR face filters use the device's camera to overlay visual and/or video content on users' faces (Appel et al., 2020). Snapchat's rapid growth, reaching 238 million daily active users in 2020 (Statista, 2020b), can be fairly attributed to their continuous creation of AR face filters (Boland, 2019). While Snapchat was the first SNS to enable AR face filters, Instagram and Facebook have recently got on this bandwagon (Neuburger et al., 2018). AR face filters have a similar functioning in all SNSs: the smartphone camera recognises users' faces and their environment, and they choose the filter that is added either to their faces or the environment. At early stages, AR face filters were generic and mostly developed by the specific SNS. However, brands are increasingly investing in creating AR face filters to promote their products (Rauschnabel et al., 2019), and some SNSs currently allow brands, public figures, celebrities, and other creators to make original AR filters (e.g., Spark AR [https://sparkar.facebook.com/ar-studio/]). Thus, both brands and SNSs seem to be committed to generate content by means of AR face filters.

Previous literature about AR in marketing and communications has focused on its positive impact on industries such as retailing (e.g. Heller et al., 2019; Scholz & Duffy, 2018) and tourism (e.g. Chung et al., 2015). Specifically, one of the most analysed AR-based tools are virtual try-ons (Hilken et al., 2017). These technologies are mainly implemented in retail settings, and allow consumers to virtually "try-on" a product by means of AR before making their purchasing decision. The efficacy of virtual try-ons, compared to traditional web-based product presentations, has been analysed by prior research (e.g. Yim & Park, 2019). Past studies have also found utilitarian and hedonic benefits of using virtual try-ons (Baek et al., 2018; Hilken et al., 2017). However, the impact of AR face filters on SNS users' experiences remains unexplored. This research aims to analyse the users' perceptions of AR face filters and their influence on behavioural intentions. Adopting a process theory approach (Van de Ven & Poole, 1995) and a utilitarian-hedonic perspective (Van der Heijden, 2004), this study investigates how the characteristics of AR face filters (i.e., originality, aesthetics, interactivity) influence the users' perceptions of usefulness and enjoyment, and their subsequent impact on behavioural intentions towards the brand and towards using a SNS that enables the use AR face filters. The results of the empirical study show that, compared to AR face filters which are not featured by brands, branded AR filters are perceived as more original, with more aesthetic quality, and more interactive. These perceptions influence perceived usefulness and enjoyment, which subsequently determine behavioural intentions. Interestingly, the perceived usefulness of AR filters has a strong impact on users' intentions towards the brands, whereas perceived enjoyment is more influential on intentions towards SNS. Theoretical and managerial implications derived from these findings are discussed.

2 Theoretical Development

AR face filters are defined as unique interactions in which AR elements are applied to the user's face or surroundings on SNS, enhancing or changing what can be seen in the actual environment (Rios et al., 2018). Unlike virtual try-ons that are mainly implemented for product testing in retail settings, AR face filters are available for consumers on SNSs so that agents (e.g., brands, influencers) use them to communicate and disseminate information in an enjoyable way. Some successful examples of branded AR filters on SNSs, like Taco Bell, which was viewed over 224 million times on the day of its launching (IAB, 2019), reveal the potential of AR filters for brands to reach and impact on their target audiences.

Given the novelty of AR face filters and the lack of studies investigating their influence, this study follows a process theory approach (Van de Ven & Poole, 1995) to analyse the impact of AR face filters on behavioural intentions towards SNS and brands (Fig. 1). In behavioural research, the process theory is widely used to analyse "how" some phenomena take place (Chiles, 2003), and it helps understand the underlying mechanisms that lead to the occurrence (or not) of certain outcomes (Van de

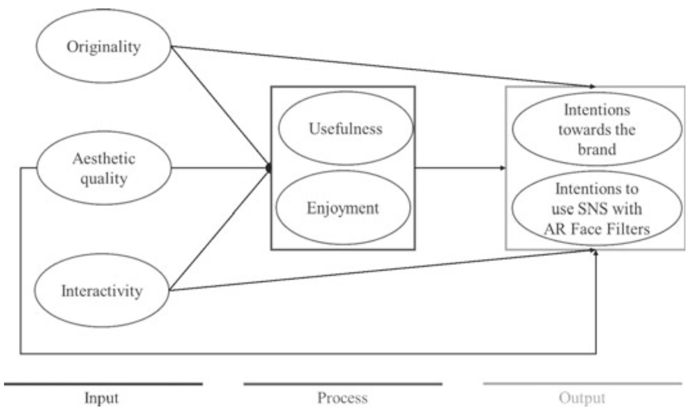

Fig. 1 Conceptual framework

Ven & Poole, 1995). Process theories serve to explain how some events or outcomes happen as a result of certain input states, following a set of processes throughout their development (Jung et al., 2015). This approach has been previously applied in research with immersive technologies. In the specific context AR, Jung et al. (2015) analysed how perceptions resulting from the elements of an AR application (content quality, system quality, personalized service quality) affected the intention to recommend the application through the satisfaction generated during the experience.

AR face filters can be created and posted by multiple players, such as influencers, anonymous users, brands or the SNS itself. Taking into account that brands (e.g. Game of Thrones, Adidas) are using AR face filters on SNSs as a new way of communicating and interacting with consumers, this research differentiates between branded and non-branded AR face filters to analyse their impact on the users' perceptions of originality, aesthetic quality and interactivity. These three variables are regarded as the input states of the process theory approach (Fig. 1). Originality is the degree to which users perceive some contents as unusual, innovative and sophisticated (Casaló et al., 2017a). Aesthetic quality refers to the vividness and visual appeal of the digital content (Pantano et al., 2017). Interactivity relates to the users' capacity to modify and manipulate the contents that are displayed in the technology-mediated environment (Steuer, 1992). Currently, brands need to focus on their efforts on SNSs to engage customers (Mishra, 2019), so they implement innovative formats as AR filters to craft superior experiences (Scholz & Smith, 2016). For this reason, 90% of large consumer advertisers are using, or are planning to use, AR in their marketing campaigns (Bona et al., 2018). These high-end brands have the capacity of investing a great amount of resources in developing branded content. Thus, AR face filters featured by brands can be expected to be more elaborated, unique, and sophisticated than those featured by the SNS and other users. Consequently, perceptions of originality, aesthetic quality, and interactivity, should be higher for branded AR face filters than for non-branded AR face filters:

H1: Branded AR face filters (vs. non-branded AR face filters) will have a positive effect on users' perceptions of (a) originality, (b) aesthetic quality and (c) interactivity, of the AR face filters.

The enjoyment-usefulness approach (Van der Heijden, 2004) suggests that the use of technologies can generate both utilitarian and hedonic reactions in users. Both variables are considered as the process in the model (Fig. 1). Perceived usefulness is the degree to which the use of a particular technology or system will help users to obtain convenient and useful information (Basak & Calisir, 2015; Casaló et al., 2017b). Perceived enjoyment refers to the fun that users obtain with the use of a particular technology (Van der Heijden, 2004). Additionally, behavioural intentions are regarded as a proxy of how users are planning to behave in the reality (Flavián et al., 2019b; Venkatesh et al., 2003). Behavioural intentions are the outcomes in the research model (Fig. 1). For brands, behavioural intentions refer to the probability that users will perform actions such as purchasing or recommending the brand. For SNSs, this research considers users' intention to use a SNS that enables the use of AR filters. The use of AR face filters is relatively novel; not all the SNSs have implemented AR filters. Recent reports show the growth of several SNSs which have implemented AR face filters (e.g. Instagram, Snapchat; Statista, 2020b). Whether coincidence or not, the rising of these SNSs is coupled with the availability of AR filters. Thus, it seems interesting to analyse if users appreciate this functionality of a SNS and if they would consider taking part in a SNS that enables them to use of AR face filters. If so, the effective implementation of AR face filters may represent a source of competitive advantage for a SNS.

Previous research has supported the positive effect of originality on perceived usefulness (McLean & Wilson, 2019), enjoyment (Casaló et al., 2017a), and behavioural intentions (Moldovan et al., 2011). Similarly, aesthetic quality has been positively related to usefulness and enjoyment (Cyr et al., 2006), as well as behavioural intentions (Marasco et al., 2018). Also, Yim et al. (2017) found a positive relationship between interactivity and usefulness, enjoyment, and behavioural intentions. Therefore, this research extends previous findings and proposes that the perceptions of originality, aesthetic quality, and interactivity of branded AR face filters will generate positive perceptions of usefulness and enjoyment, as well as enhanced behavioural intentions towards the brand and the SNS. All these features of the AR filters add value to the experience with the SNS (Appel et al., 2020) which, in turn, will foster users' processes and outcomes.

H2: The perceived originality of a branded AR face filters will have a positive effect on users' (a) perceived usefulness, (b) perceived enjoyment, (c) intentions towards the brand and (d) intentions to use a SNS with AR face filters.
H3: The perceived aesthetic quality of the branded AR face filters will have a positive effect on users' (a) perceived usefulness, (b) perceived enjoyment, (c) intentions towards the brand and (d) intentions to use a SNS with AR face filters.
H4: The perceived interactivity of the branded AR face filters will have a positive effect on users' (a) perceived usefulness, (b) perceived enjoyment, (c) intentions towards the brand and (d) intentions to use a SNS with AR face filters.

Finally, when users enjoy and obtain useful benefits from their interaction with systems, they are prone to develop positive responses (Casaló et al., 2017b; Kwon & Wen, 2010). Previous research has found that users obtain both utilitarian and hedonic value when using AR (Baek et al., 2018; Hilken et al., 2017). Particularly, users may obtain enjoyable experiences with the use of branded-AR face filters (Phua & Kim 2018; Rios et al., 2018), and these filters can also provide them with useful information about their products/services (Grewal et al., 2020), fostering of their behavioural intentions. Therefore, the positive impact of users' perceived usefulness and enjoyment of using branded AR face filters should translate into favourable behavioural intentions towards the brand and the SNS:

H5: Perceived usefulness of branded AR face filters has a positive effect on users' (a) intentions towards the brand and (b) intentions to use SNS with AR face filters.
H6: Perceived enjoyment of branded AR face filters has a positive effect on users' (a) intentions towards the brand and (b) intentions to use SNS with AR face filters.

3 Methodology

The hypotheses were tested through an online survey. The services from a market research agency were hired to distribute the survey. After a brief explanation about AR face filters and its use on SNSs, participants were asked if they had ever used them; if the answer was affirmative, they indicated whether the filters were featured by a brand or not. The participants who had never used AR face filters were filtered out, and after providing the socio-demographic information, were thanked and dismissed. Out of initial sample of 622 individuals, 430 reported a previous experience with AR face filters, consisting of 161 users of brand-featured AR face filters and 269 users of non-branded AR face filters.

The participants (n = 430) answered general questions about their use of SNSs and AR face filters. Also, they responded to a set of questions regarding their perceptions regarding their previous experience with the filters (either branded or non-branded), and indicated their behavioural intentions. The participants with previous experiences with branded AR face filters answered additional questions. Specifically, they had to classify the filters they had used according to several pre-specified categories, and reported additional perceptions and behavioural intentions towards the brands. Finally, socio-demographic information was gathered from all the participants.

The questionnaire included scales adapted from previous literature for measuring the variables of interest: originality (Moldovan et al., 2011), aesthetic quality (Pantano et al., 2017), interactivity (Animesh et al., 2011), usefulness (Kwon & Wen, 2010), enjoyment (Van der Heijden, 2004), behavioural intentions towards brands (Casaló et al., 2017b; Flavián et al., 2020; Lu et al., 2014) and intentions to use a SNS that enables AR face filters (Venkatesh et al., 2003). These questions used 7-point Likert scales (from 1 = "strongly disagree", to 7 = "strongly agree").

4 Results

As previously stated, the participants who had used branded AR face filters were asked about the specific brand name. Those who did not remember any brand or gave inaccurate answers were screened out. In addition, there was a low number of responses from people older than 55 years old and with no educational level, so they were also removed from the dataset in order to avoid biases in the analysis due to these potential outliers. Thus, the total valid sample consisted of 400 AR face filters users (68% female; 85.5% were under 26 years old), corresponding to 256 users of non-branded AR face filters and 144 users of branded AR face filters.

Before testing the proposed model, descriptive statistics were calculated to examine the general use of SNSs and AR face filters among the participants. Table 1 displays the descriptive data for all the users AR face filters, and differentiates between branded AR filters and non-branded AR filters. As can be observed in Table 1, users of AR face filters are heavy users of SNSs (56% use social media for more

Table 1 General use of SNSs and AR face filters

	Total sample (n = 400) (%)	Non-branded AR filters (n = 256) (%)	Branded AR filters (n = 144) (%)
Overall daily use of SNS			
Less than 1 h	8.5	11.7	2.8
1–2 h	35.5	37.9	31.3
3–4 h	39.5	39.1	40.3
More than 4 h	16.5	11.3	25.7
Use of specific SNS			
Facebook			
No profile	10.3	10.2	10.4
One day per week or less	50.5	51.2	49.3
2–5 days per week	20.2	20.7	19.4
6–7 days per week	19.0	18.0	20.8
Twitter			
No profile	21.8	23.0	19.4
One day per week or less	44.3	44.1	44.5
2–5 days per week	15.3	17.2	11.9
6–7 days per week	18.8	15.6	24.3
Instagram			
No profile	3.3	3.9	2.1
One day per week or less	7.3	9.8	2.8
2–5 days per week	14.6	16.0	11.8
6–7 days per week	75.0	70.3	83.3
Snapchat			
No profile	25.0	30.5	15.3
One day per week or less	58.0	60.2	54.2
2–5 days per week	9.5	5.5	16.7
6–7 days per week	7.5	3.9	13.9
TikTok			
No profile	54.8	57.4	47.2
One day per week or less	41.8	39.4	45.8
2–5 days per week	3.8	3.9	4.9
6–7 days per week	0.8	2.0	2.1
YouTube			

(continued)

Table 1 (continued)

	Total sample (n = 400) (%)	Non-branded AR filters (n = 256) (%)	Branded AR filters (n = 144) (%)
No profile	5.3	6.3	3.5
One day per week or less	14.8	15.2	13.9
2–5 days per week	42.3	42.9	40.9
6–7 days per week	37.8	35.5	41.7
Use of face filters on SNS[a]			
Facebook	6.1	3.9	10.1
Instagram	92.2	89.0	97.9
Snapchat	83.0	83.7	81.9
TikTok	6.5	4.6	9.2
Other	0.1	0.1	–
Frequency of use of AR face filters			
Less than once a month	42.3	52.7	23.6
At least once a month	20.5	21.5	18.8
At least once a week	25.0	20.7	32.6
Every or almost every day	12.3	5.1	25.0

[a]Only those with profile in the SNS

than 3 h every day). Instagram is the most frequently used SNS, especially for the participants with previous experience with branded AR face filters. The data also reveals that Instagram and Snapchat are the most popular SNSs for using AR face filters. Focusing on these SNSs, participants reported more experience with branded AR face filters on Instagram than on Snapchat, while this difference is not that evident for non-branded AR filters (Table 1). Users who had used branded (versus non-branded) AR filters reported a higher frequency of use. Finally, branded AR face filters were sorted out in the following categories: fashion (49.3%; e.g., Desigual), cosmetics and makeup (68.8%; e.g., MAC), food (28.5%; e.g., Lays), sports (45.8%; e.g., Adidas), TV shows (41.7%; e.g., Game of Thrones), films (49.3%; e.g., Harry Potter), and entertainment (41.7%; e.g., Netflix).

After carrying out the regular procedures to validate the scales (Hair et al., 2010), mean values of the perceptions of originality, aesthetic quality, and interactivity were calculated to test H_1. The originality of branded AR face filters ($M = 4.17$, $SD = 1.48$) was significantly higher than of non-branded AR face filters ($M = 3.79$, $SD = 1.46$; $t_{(398)} = 2.468$, $p < 0.05$). Perceived aesthetic quality was also significantly higher for branded AR face filters ($M = 4.86$, $SD = 1.54$) than for non-branded AR face filters ($M = 4.47$, $SD = 1.49$; $t_{(398)} = 2.486$, $p < 0.05$). Finally, users of branded AR face filters perceived higher interactivity ($M = 4.16$, $SD = 1.76$) than users of non-branded AR face filters ($M = 3.70$, $SD = 1.78$; $t_{(398)} = 2.445$, $p < 0.05$). Therefore, H1 was supported.

To test hypotheses 2–6, the main effects proposed in the model were estimated with the software SmartPLS 3.2.9. (bootstrapping 5000 iterations; Ringle et al., 2015). The analysis included the sample of branded AR face filters (n = 144). The results appear on Table 2. Perceived originality positively influenced the perceived usefulness and enjoyment, but it had no direct impact on behavioural intentions. Thus, H_{2a} and H_{2b} are supported, but H_{2c} and H_{2d} must be rejected. Perceived aesthetic quality affected enjoyment and the intentions to use a SNS that enables the use of AR face filters, supporting H_{3b} and H_{3d}. However, aesthetic quality did not affect usefulness (H_{3a}) and behavioural intentions towards the brand (H_{3c}). The influence of perceived interactivity on usefulness was significant and strong, and it also had a significant but lower effect on enjoyment and behavioural intentions towards the brand (Table 2). Support to H_{4a}, H_{4b} and H_{4c} was found (H_{4d} was not supported). Perceived usefulness affected both behavioural intentions (supporting H_{5a} and H_{5b}), being higher the effect on behavioural intentions towards the brand than towards the SNS (Table 2). Conversely, perceived enjoyment positively influenced the intention to use a SNS that enables AR face filters, while it had no impact on intentions towards brands. Thus, H_{6b} was supported, but H6a was rejected.

Given the lack of direct effects of perceived originality, aesthetic quality, and interactivity, on behavioural intentions, mediation analyses were implemented to test whether the effects could be established indirectly. The estimation indicated that originality affected the intention to use a SNS that enables AR face filters indirectly through enjoyment (coeff. = 0.100; t-value = 2.042). Also, the perceived aesthetic quality had an indirect influence on the intention towards the SNS through enjoyment (coeff. = 0.135; t-value = 2.333). Finally, perceived interactivity affected the

Table 2 Results of the conceptual framework

Antecedent	Dependent variables							
	Usefulness		Enjoyment		Intentions towards the brand		Intentions towards the SNS	
	Coeff	t	Coeff	t	Coeff	t	Coeff	t
Originality	0.263*	2.305	0.245*	2.166	−0.230 (ns)	1.811	−0.016 (ns)	0.136
Aesthetic quality	0.146 (ns)	1.234	0.329**	2.968	0.094 (ns)	0.724	0.226*	2.023
Interactivity	0.411***	5.684	0.222**	3.067	0.238*	2.552	−0.029 (ns)	0.420
Usefulness					0.306**	2.964	0.176*	2.130
Enjoyment					0.184 (ns)	1.892	0.409***	4.346
R^2	0.458		0.451		0.302		0.442	

Note *** Coefficients are significant at the 0.001 level; ** Significant at the 0.01 level; * Significant at the 0.05 level; (ns) Non-significant intentions towards the SNS through enjoyment (coeff. = 0.091; t-value = 2.418), and the intentions towards the brand through usefulness (coeff. = 0.126; t-value = 2.646).

5 Discussion

First, the results of the descriptive analysis show that users of AR face filters are intensive in their use of SNSs, and they mainly use these filters on Instagram and Snapchat. These SNSs were pioneer in the implementation of AR filters and invest heavily in them. This fact shows that certain SNSs, distinguished by their strong visual nature (Casaló et al., 2017b), may be more suitable for the implementation of AR face filters. Additionally, it seems that Instagram may be especially suitable for promoting brands through AR face filters, given that almost all the Instagram users in the sample of participants had previous experience with branded AR face filters.

Second, the results show that branded AR face filters are perceived as more original, of higher aesthetic quality, and more interactive than non-branded AR face filters. This may be due to the fact that brands can devote a great amount of resources to develop sophisticated content (e.g., becoming a White Walker from Game of Thrones), compared to the AR filters that can be provided by a SNS or other users (e.g., dog ears). Third, originality, aesthetic quality, and interactivity have a notable explanatory power of the perceived usefulness and enjoyment of AR face filters. Usefulness is mostly determined by interactivity, whereas aesthetic quality had no impact; conversely, aesthetic quality is the strongest predictor of enjoyment. Originality has similar effects on usefulness and enjoyment. The interaction with the content allows users to obtain a greater volume of information about a brand (Yim et al., 2017), while aesthetics is an element that encourages the generation of fun experiences (Cyr et al., 2006). In any case, AR filters should be original to attract the users' attention (Pieters et al., 2002) and to promote their usefulness and enjoyment. Finally, behavioural intentions towards brands and SNSs may be shaped differently. The analysis shows that the utilitarian route (i.e. usefulness) may be more important than the hedonic route (i.e. enjoyment) for users to develop favourable intentions towards brands. Users may need to perceive that using branded AR face filters is somehow useful in order to favour that brand. However, the opposite may be the case for SNSs: enjoyment has a stronger impact than usefulness on the intentions to use a SNS that enables the use of AR face filters. This result may be due to the hedonic nature of SNSs (Casaló et al., 2017b), so users are motivated to consume branded content when it is enjoyable (Muntinga et al., 2011).

6 Implications, Limitations and Future Research Lines

The results of the analysis offer implications research and practice. At the theoretical level, this study contributes to the previous AR literature by being one of the first that empirically analyses the impact of AR face filters as a communication tool on SNSs. Following a process theory approach, this research examines the influence of the inputs states generated by the experiences with AR face filters (perceived originality, aesthetic quality and interactivity) on the outputs (behavioural intentions towards brands and SNSs) through a process driven by utilitarian-hedonic paths. The results highlight the potential of AR face filters for both brands and SNSs, so this study may serve as the basis for future research to advance in the knowledge about this innovative tool. In addition, the process theory approach is proven to be useful for understanding how users behave with immersive technologies on SNSs.

As for managerial implications, brand and SNSs managers are encouraged to embrace AR face filters as part of their communications strategies in social media. For brands, the interactive nature of AR face filters should be emphasised. For example, branded AR filters should require the users to perform some actions (e.g., facial gesture, move around) that cause a reaction on the AR face filter. In this way, brands can enhance the users' perceived usefulness resulting from their filters, leading to positive behaviours towards the brands. For SNSs managers, it is important that the AR face filters generate enjoyable experiences. Users prefer AR filters that make them have a fun experience on the SNS (Rios et al., 2018). To this end, managers should invest in the aesthetic quality of the AR face filters, which has a strong impact on enjoyment. Additionally, they can encourage users to vote for their favourite filters to foster co-creation of value (Spark AR [https://sparkar.facebook.com/ar-studio/]; Lens Studio [https://lensstudio.snapchat.com/]). All these actions should be done while keeping the originality of the AR face filters at a high standard to offer valuable experiences. Overall, content developers must consider which should be the focus of their AR face filters (utilitarian or hedonic), and emphasize their interactive/aesthetic/original content accordingly, to favour behavioural intentions.

This research has several limitations that offer possibilities for future research lines. First, the questionnaire asked participants for their general experience with AR face filters. In addition, although the SNSs on which participants had used AR face filters were gathered, the specific SNS and filter were not controlled; thus, the variability of the answers limits the validity of the findings. Future studies based on experimental methodologies should be implemented in order to control for the specific features of the AR face filter (e.g., interactive versus non-interactive), SNS (e.g., generic versus specialised), and user experience (e.g., utilitarian versus hedonic). Additionally, privacy concerns and perceived intrusiveness resulting from the experiences with AR face filters have not been addressed (Feng & Xie, 2019). Future studies should analyse how these issues, which may have a negative influence on the use and acceptance of immersive technologies, affect user experience in the specific context of AR face filters. Despite these limitations, this study can stimulate the debate in the literature on this flourishing topic, and can serve as the basis for AR face filter developers to generate better experiences with these tools.

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Immersive Technology in Storytelling, Art Exhibitions and Museums

Can You Make the Cut? Exploring the Effect of Frequency of Cuts in Virtual Reality Storytelling

Aleksandra Zheleva, Jolien De Letter, Wouter Durnez, Sven Rousseaux, and Lieven De Marez

Abstract Straight cuts are a storytelling tool that is used to direct the viewer's attention towards the main events of the plot. This research evaluated the effect of frequency of straight cuts that are controlled by the system (rather than by the viewer) on the viewer's experience of VR (i.e., presence, narrative immersion, sense of agency, simulator sickness, and enjoyment). We used both quantitative and qualitative methods to examine the viewer's experience and understanding of a one-minute long VR movie in three versions (i.e., 15 cuts/min; 8 cuts/min; no cuts). The study illustrates that sense of agency, enjoyment, and understanding of the story are influenced by the frequency of straight cuts. Also, straight cuts focus viewers on events in the story, which in turn helps them understand the plot better. However, we need a balanced frequency of cuts to preserve the sense of agency of users. Finally, the study highlights that the viewers' experience is a result of an interplay between narrative immersion, sense of agency, and presence.

Keywords Virtual reality (VR) · Storytelling · Straight cuts

1 Introduction

Virtual reality (VR) uses enhanced displays to offer an interactive viewing experience of 3D virtual worlds to the user. The rapid development of VR and its increased availability to more customers have turned VR storytelling into the next frontier of customer experiences. However, to exploit VR's full potential and develop intriguing content, we need to understand that the way events are presented in traditional media (i.e., film and TV) is different in VR (Newton and Souton, 2016).

Arguably the biggest difference between traditional media storytelling and storytelling in VR is the linear design of plotlines presented in the traditional media.

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More specifically, in a movie, the delivery of the story consists of the content creator presenting viewers with a track that they follow to get from the start of the story to the finish. However, if we want to retain VR's inherent added value (i.e., the user's ability to look and/or move around in the environment) this linear presentation of events cannot work. In VR the user is actively choosing how their experience of the story will develop. Thus, VR storytelling requires an "engage, don't show" creator mindset (Newton and Souton, 2016; Zhang et al., 2018).

One way to engage viewers and make sure they follow the story is by using straight cuts as an editing tool. Straight cuts (i.e., when the video moves to a new shot) are often used as a scene transition technique both in traditional media and in VR storytelling. Yet, the use of straight cuts in VR might have a different effect on the viewer's experience. More specifically, using straight cuts to "forcefully" change the point of view of the user might be breaking one of the key features in VR—autonomy.

In VR, the user's ability to move autonomously within the virtual world is a core attribute of the user experience, and research has shown that scene transitions can hinder this experience. Zhang et al. (2018) showed that VR users find cuts to be a boring method of transition. However, cuts were also shown to be the method that yielded the highest comfort, immersion, and perception of continuity compared to other transitional methods such as iris wipes (i.e., a film transition where one shot replaces another by taking the shape of a growing or shrinking circle). Thus, we must further explore ways to use straight cuts as a VR technique that can incorporate both the presentation of events and the autonomy of the user. As the director of the VR multi-part series, Invisible (2016) Doug Liman comments:

> We had to rethink the way we were telling stories because when you just take a traditional scripted scene out of any TV script or movie script and shoot it in VR, it's going to be less compelling than what was shot in 2D. You'll feel like you're watching a video of a play. VR should be more emotionally involving, but that doesn't happen automatically by just taking a VR camera and sticking it onto what would be a traditionally blocked scene for 2D. (in Robertson, 2016, para 6)

The current research investigates the role of straight cuts as a storytelling tool in VR. More specifically, we look into the effect of frequency of straight cuts (15 cuts/min, 8 cuts/min, and no cuts) on the viewer's sense of agency, presence, narrative immersion, perceived enjoyment, and simulator sickness experienced in VR. Exploring the modulation of the frequency of the cuts would help us gain more insight into the effective utilization of straight cuts as a scene transition tool in VR storytelling.

2 Theory and Hypotheses

The interactive nature of VR invites the viewer to explore the virtual environment (VE) by walking and looking around. This movement, combined with the scene transition (i.e., straight cut), may influence the viewer's feeling of simulator sickness (e.g., fatigue, eye strain, dizziness) (So et al., 2002). Thus, we expect that the higher the frequency of straight cuts is, the higher the simulator sickness will be.

In the context of the current study, straight cuts are abrupt changes of point of view (POV), controlled by the system rather than by the user. The automated nature of straight cuts forces the viewers to look at the POV that is imposed upon them by the director and thus reduces their sense of agency (i.e., the perception that you can self-determine what to do). Hence, we predict that sense of agency will be negatively affected by the number of straight cuts. Furthermore, Huang et al. (2019) showed that when participants experience more sense of agency in VR, they also enjoy their VR experience more. Therefore, we predict that sense of agency has a direct positive effect on perceived enjoyment.

Presence in VR happens when a user believes that they are in the VE as shown by their realistic reaction to stimuli (e.g., ducking down to avoid being hit by a spaceship coming towards you) (Nilsson et al., 2016). Research so far has illustrated that users feel more present in a VE when they experience a greater sense of agency (Huang et al., 2019). Consequently, we also expect to find this effect in the current study. Another factor that might influence presence is simulator sickness. It has previously been shown that experiencing symptoms of simulator sickness such as nausea or fatigue can pull the viewers' attention towards their physical state and away from the virtual environment (VE) they are in (Kuze & Ukai, 2008). Subsequently, we hypothesize that we will find a direct negative effect of simulator sickness on presence.

Additionally, narrative immersion occurs when the viewer is intensely preoccupied with the unfolding narrative (Nilsson et al., 2016). Studies show that users feel more immersed in the narrative and present in VR when they have more freedom in the VE (Newton and Souton, 2016). Hence, we expect that the fewer the number of cuts in a VR story, the more people will feel free to choose where to look thus strengthening their narrative immersion. Moreover, Waterworth et al. (2015) suggest that a relatively high degree of narrative immersion is a prerequisite for experiencing presence in VR. Therefore, we can expect that if viewers are more immersed in the narrative, then they will also feel more present in the VE. Finally, Lee et al. (2013) also illustrated that the more the user feels present in the VE, the more they enjoy their experience. So, we expect to find a similar effect in the current study. All expected relationships are summarized in Fig. 1.

3 Methodology

3.1 Design and Stimulus Material

We conducted a within-subject study. All participants used the HTC Vive Pro Eye head-mounted display (HMD) to view a one-minute long movie. The HMD has a resolution of 1440 × 1600 pixels per eye (2880 × 1600 pixels combined) and a

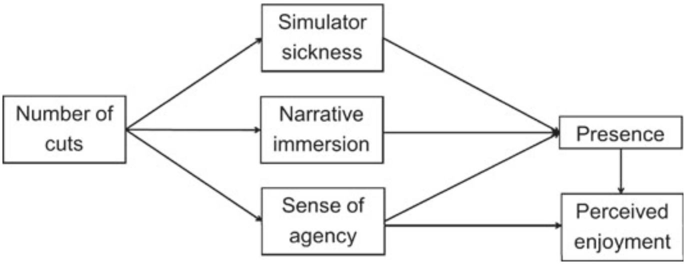

Fig. 1 Conceptual model

refresh rate of 90 Hz. Furthermore, the HMD was wireless, which allowed the users to freely explore (i.e., walk around) the VE within the confound of the VR play area (approx. 2 × 2 m).

The movie was created in Unity 3D (Fig. 2). It tells the story of a businessman who walks into an office building, seemingly waiting for someone. After a few seconds, the man receives a text message and puts down his briefcase to look at his phone. Then, a woman walks out of the elevator—she waves to the man and beckons him to join her. The man looks down to pick up his briefcase but finds it has gone missing. The movie includes background audio (lobby noise, general chatter sounds), which was present at all times, and the sound of an elevator arriving, which was played when the woman from the elevator arrived in the scene. Each participant viewed three versions of the story: (1) 15 cuts/min version; (2) 8 cuts/min version and (3) no cuts version. The presentation order was counterbalanced to avoid sequence effects.

Fig. 2 Stills from scenes of the VR movie

3.2 Participants

Data was gathered from 33 participants (23 females) with a mean age of 27.61 years ($SD = 7.71$). Twenty-four participants indicated that they had previous experience in VR – watching movies ($n = 10$), playing games ($n = 8$), participating in unique experiences ($n = 4$), and using it for educational purposes ($n = 2$).

3.3 Procedure and Measurement Instrument

The experiment took 45 min and started with a short briefing and consent form procedure, followed by three experimental blocks. In Block 1 participants viewed a first version of the video, after which they participated in a semi-structured interview that explored their comprehension of the story (e.g., could you describe in your own words what happened in the story you just saw?). Then, participants filled in a questionnaire that measured simulator sickness (Kennedy et al., 1993), presence (Usoh et al., 1999), sense of agency (Sheldon et al., 1996), narrative immersion (Tcha-Tokey et al., 2016) and perceived enjoyment (Jang & Park, 2019). In Block 2, participants viewed another version of the content and completed the same questionnaire. Block 3 consisted of viewing a third version of the movie, filling in the questionnaire, and participating in a second semi-structured interview that aimed to understand if they noticed the difference in versions, which version they enjoyed the most, and in which version they felt most disoriented.

4 Results

To test if the frequency of cuts had a significant effect on the user's experience in VR we ran a series of ANOVAs with the questionnaire data. We found no significant differences. In contrast, the qualitative data showed that participants experienced different levels of enjoyment, control, disorientation, and understanding of the story. We asked participants to rank the video versions from most to least enjoyable. In the analysis, we assigned three points to the version that a participant said they enjoyed the most, two points to the version they rated as second most enjoyable, and one point to the video version they enjoyed the least.

The no cuts version was the most enjoyable (79 points). One participant said that they liked this version the most because they "had more control and could decide where [they were] looking". These findings supported the results from the quantitative data analysis that sense of agency has a direct positive effect on perceived enjoyment of ($b = 0.68$, $SE = 0.31$, $p < 0.05$). On average, the 8 cuts version was rated second best (52 points). However, comments regarding this version were mixed. Some participants found that "the story was more fluid, [and] there was less distraction (referring to the cuts)". Others still felt disoriented and did not like the cuts as they thought they felt "unnatural". Overall, participants liked the balance between being moved around but "not too much" because they had "more time to look at things". Participants ranked the 15 cuts version the least enjoyable (40 points). They indicated that the multiple cuts forced them to "refocus on the events, which broke [their] immersion and was disorientating". Often participants expressed confusion and disorientation as a result of the number of cuts: "I was looking at him and then suddenly he was at my right."; "I felt disoriented because I was moved a lot". On the other hand, others mentioned that in this version they "could see more" and received "more information about the environment".

Also, after viewing all three video versions, 30.3% of the participants ($n = 10$) did not notice the main event in the story (i.e., the briefcase going missing). This could be because when the attention of participants was not explicitly directed towards specific events via the use of straight cuts, they did not know where to look to follow the story. Indeed, a participant noted that in the version with no cuts "you miss a lot of things". Overall, 78.8% of the participants ($n = 26$) noticed the difference between the no cuts version and the other two versions. Often the viewers referred to the straight cuts as times when they were "dragged around [the environment]" or "pulled towards a character" and most frequently as a "change of viewpoint".

Finally, we a series of linear regressions to investigate the relationships illustrated in the model in Fig. 1. The analysis confirmed that both sense of agency ($b = 0.71$, $SE = 0.25, p < 0.01$) and narrative immersion ($b = 0.96, SE = 0.21, p < 0.001$) had a direct positive effect on presence. Yet, simulator sickness did not explain significant amount of the variance in presence ($p = 0.87$). Furthermore, presence did not seem to have a significant effect on perceived enjoyment ($p = 0.28$). However, sense of agency had a significant effect on perceived enjoyment ($b = 0.70$, $SE = 0.27$, $p < 0.05$).

5 Conclusion and Discussion

This study illustrates that the frequency of straight cuts influences sense of agency, enjoyment, and understanding of the story. Also, straight cuts can help focus viewers on events in the story resulting in a better understanding of the plot. However, the frequency of straight cuts must be balanced so that viewers do not feel out of control.

These findings provide practical guidelines for content creators of VR stories. More specifically, the results outline the importance of keeping the balance between influencing the audience's choice of where to focus without overburdening them with that choice. Therefore, we can conclude that straight cuts are necessary to direct the viewers' attention to elements of the story that are important for its understanding. However, their rhythm (i.e., frequency) should be used in a non-intrusive way that minimizes the possibility of the viewer to feel controlled and/or disoriented.

This study also contributes to the literature by testing a more comprehensive model that explores the overall experience of users in VR. For instance, the study showed that sense of agency and narrative immersion both directly affect the presence of viewers in a VE. This finding encourages the further evaluation of more comprehensive models of user experience. However, all those factors are related to the viewer's perception and research has shown that other, more objective VR features can also influence one's experience in VR.

For instance, Elmsley et al. (2017) have shown that the adaptiveness of sound in VR can affect the viewers' level of immersion. Also, Elbamby et al. (2018) demonstrated that network quality can have a negative impact on the viewers' experience in VR. Thus, it will be beneficial if future research identifies a more thorough set of factors that affect the experience of viewers in VR. Ideally, an exhaustive list of such impact factors would cover different facets of the VR experience (i.e., user, content, and system-related) (Reiter et al., 2014). Additionally, it will be useful to conduct further studies to model the relationships between the identified influencing factors.

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Incorporation of Augmented-Reality Technology into Smartphone App for Large-Scale Performance Art

Chun-I. Lee, Fu-Ren Xiao, and Kai-Ting Kao

Abstract Performance art is generally physical in nature. In recent years, the development of augmented-reality (AR) technology has enabled the merge of the virtual and the real to present novel visual effects. However, incorporations of AR into performance art are generally shown to audiences on large screens, which designates the audience a passive role. Using the example of 'Epitome of Time', a performance at the Da Guan International Performing Arts Festival, the researchers experimented with a smartphone application (app) that can incorporate AR into stage performances. The app features the following functions: (1) A projected image in the performance hall served as the AR recognition target; audience members could scan the image with their smartphones, generating virtual objects that they could interact with in the space around them. (2) The AR served as a marketing method before the performance. (3) Push notifications sent audience members reminders of show times. This study adopted the spiral model of action research method presented by Lewin, the steps of which include planning, action, observation, and reflection. The interactive re-examination of each process forms a feedback loop for app development. We then put forward suggestions to serve as reference for future incorporations of smartphones and AR into large-scale performance art. We also predict which emerging AR equipment could create more possibilities for AR interaction in this field.

Keywords Augmented reality · Smartphone app · Performance art · Action research

1 Introduction

'Epitome of Time' is an interdisciplinary art performance achieved under the guidance of president of the National Taiwan University of Arts (NTUA), Dr. Chih-Cheng Chen. Combining dance, drama, music, art, and technology, the performance was held at the NTUA Performing Arts Center on December 6 and 7, 2019. For

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most stage performances, smartphones are considered to be an interference. Yet in today's society, smartphones are considered indispensable by many and represent the most personal technology products. In performance art, there is no distance between the performers and the audience. The performers are both the subjects and the objects of the work and they draw the audience into this multi-layered relationship (Meyer, 2009). The researchers thus attempted to turn smartphones into a part of the performance and thus an extension of the audience by enabling the audience to use their personal smartphones to extend their personal space. Through augmented-reality (AR) technology, audience members can choose how to participate in the performance space. This opens a dialogue between technology and performance art.

AR was developed in 1990 (Lee, 2012). Its positioning technology enables virtual objects to overlap with physical space, naturally incorporating the virtual into reality and even surpassing the stage space. AR technology and performance art have been successfully combined in a number of cases. For instance, the SK Wyverns of the Korea Baseball Organization used AR technology to show a giant dragon flying over their home stadium during their opening game (SK_Telecom, 2019). Marco created a 270-degree immersive experience by using virtual projections to bring audiences into fifteenth century Rome (Balich, 2018). Although these examples used AR or projection technology to combine virtual objects with reality and displayed them on big screens in real time, the role of the audience remained passive. TSRB's Augmented Environments Lab (2019) however enabled audience members to watch virtual characters on stage using smartphones and AR and also enabled the audience to participate. Technical limitations meant that only 20–30 audience members surrounding a small stage could participate, limiting the scope to the stage (Atkinson, 2019). With regard to stage positioning in AR, a number of technologies have been developed. For example, Zhang et al. (2019) used UWB positioning and Bluetooth triggering. They equipped the stage and the performers with sensors so that the virtual effects would follow the main characters. Clay et al. (2014) featuring body interactions by one of the dancers and backstage interactions by the augmented reality engineer, and conducted a study focused on achieving seamless integration between a dancer on stage and AR elements. However, this immersive positioning method for the performers' bodies requires numerous sensors, which could be cumbersome for the performers. Also, it is difficult for the audience to perceive the immediacy between the performer and the AR elements. Therefore, this study aimed to devise a means of using simple smartphone equipment to enable the audience members to perceive the AR and interact with virtual objects in a large performance hall (over 600 people).

In 'Epitome of Time', the objective was to incorporate AR technology without taking attention from the performers. Rather, the AR aspects were intended to serve as small surprises. The audience members could take up their smartphones, turn on their AR cameras, and observe the space extending from their stage to different angles and positions by controlling the gyroscopes in their smartphones. Through the screens of their smartphones, audience members could see birds flying in the air inside the performance hall and interact with hooded figures standing guard around the performance hall by clicking on them. By combining AR and smartphones, we achieved the goal of an active audience, thereby breaking the stage framework.

Much room remains for improvement, but it is anticipated that activating the audience through technology is a reference-worthy method of extending the performance stage.

2 Methodology

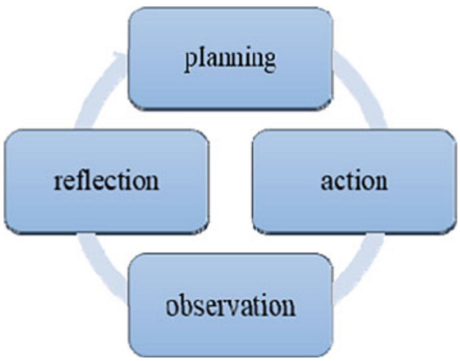
This study required the development of an app to coordinate with the stage performance. We adopted the spiral model in Lewin's action research (Lewin, 1946) to combine practice and research using the reflective actions of practical workers (Schön, 1983). During the process, we reviewed the app and corrected discovered problems to optimize the practical results. The research steps included planning, action, observation, and reflection. We then re-examined each process to form a cycle, as shown in Fig. 1.

In the planning step, the researchers discussed with the director how mobile phones can be introduced into the performance. The two main issues include: (1) How AR technology can be integrated into the performance without destroying the connotation of the performance itself. (2) How smartphone app can be used in performance marketing.

In the action step, the researchers began to conduct various technical tests and productions, including which AR technology is suitable for use in the performance hall, discuss with the director and stage lighting engineer the brightness of the performance hall scene, the material and color of the projection screen used, and the proportion of the projected image. After confirming the various tests, the research team began to make the App. The research team members include a programmer and an artist. The programmers use Unity with the Vuforia package for AR development and use Firebase Cloud Messaging for push notification function. The artist use Maya for 3D modelling, texturing, and animation.

In the observation step, the researchers observed the audience behavior on the day of the performance, including: (1) the staff guiding audience members to download the app, (2) how to use it before entering the performance hall, (3) the audience

Fig. 1 Lewin's spiral model of action research



members' reaction to the use of the app after entering the performance hall, (4) when the smartphone is about to be used to watch AR images, the audience members' reaction to taking out the smartphone.

In the reflection step, the researchers put forward reflections based on observations, reviewed the problems and reactions of the audience members' use of mobile phones in performances from the audience members' behavior, proposed ways to improve and gave some suggestions to developers who would like to develop smartphone app for large-scale performance art in the future.

The following is a detailed discussion on the four research steps.

2.1 Planning

The entire performance consisted of nine acts. The AR portion was displayed in the fifth act. After discussion with the performance team, the researchers identified the following features that the app could offer: (1) Audience members can use their smartphones to scan an icon on the stage to serve as the origin ($x = 0$, $y = 0$, $z = 0$) of the overlapping virtual space and real space(Lee, Xiao, & Hsu, 2019). For this feature, it was important to make sure that the sizes of the performance hall and the virtual space fit each other. (2) Audience members can interact with virtual objects. (3) The app can serve as a way of marketing the performance. (4) The app has a push notification function to remind audience members of the show times. The researchers employed Unity for app development, with Vuforia for AR positioning and Firebase for the push notification function. In terms of hardware, the projector was a Panasonic PT-MZ6760, and a seamless 18 m $\times$ 10 m white scrim was used for the projection screen. The distance between the white scrim and the projector was 32.56 m, as shown in Fig. 2.

2.2 Action

The action step involves development and testing of the app. As they must coordinate with the performance, the image presentations must fit the performance content and the physical space of the performance hall. The development of the app was thus divided into the following aspects:

- Combining the virtual and physical space: The scanning target was a static leafy white tree in the projected film. The researchers extracted the white tree from film and uploaded it to the online platform of Vuforia Developer to create a recognition image. The platform analyzes the augmentable rating of the image, the highest of which is five stars, and recognizes the feature distributions in the image, as shown in Fig. 3. AR scanning is affected by the environment, so we conducted testing and found that under conditions of complete darkness in the performance hall, a

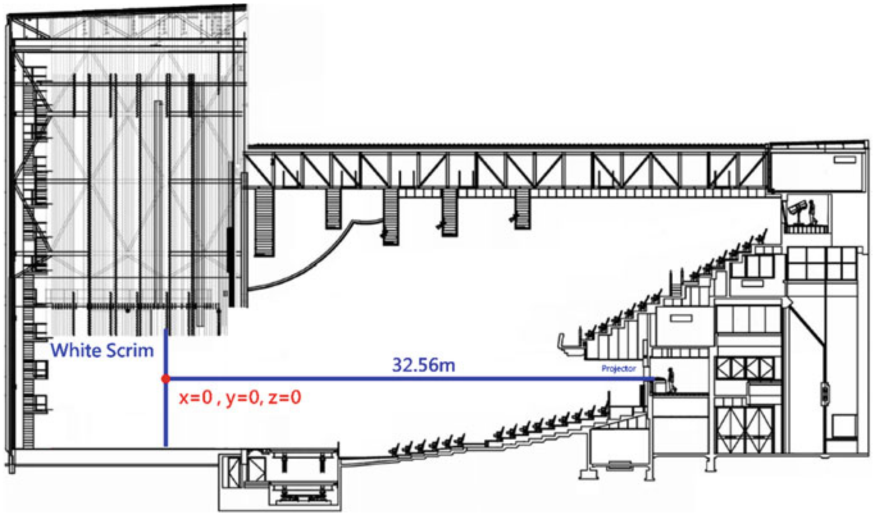


Fig. 2 Distance between white scrim and projector

Fig. 3 White tree on stage

white scrim produced the best results for projection. Tests confirmed successful scanning at all extreme locations in the performance hall (Fig. 4). The completed app was coordinated with the on-site environment with color calibrations to make sure the virtual objects fit the overall color scheme.

- Retention of virtual objects in space: It was important to ensure that the virtual objects would remain in the space of the performance hall when audience members turned their AR cameras. Therefore, the app employed the extended tracking function of Vuforia. When the audience members scanned the recognition image, the virtual objects in the surrounding space of the performance hall would remain

Fig. 4 Virtual objects displayed on smartphone screen after scanning of white tree

visible and not disappear for those with gyroscopes in their smartphones even when they turned their smartphones away from the recognition image, as shown in Fig. 5.

- Interactions with virtual objects: As intended by the director, audience members could tap the virtual objects and cause them to generate a fog (Fig. 6), gradually disappear (Fig. 7), and then reappear 15 s later.
- Marketing purpose: The download link of the app was made into a QR code accompanied by a leafless white tree with an augmentable rating of five stars (Fig. 8), which were then distributed on online platforms and various promotional materials, such promotional video (Fig. 9) and social media sites. People were prompted to download the app, use the camera function in the map to scan the white tree, and tap virtual objects to get ticket discount codes (Fig. 10). This gave people the idea that the virtual objects could be tapped on so that they would naturally interact with virtual objects during the performance. As the prompt did

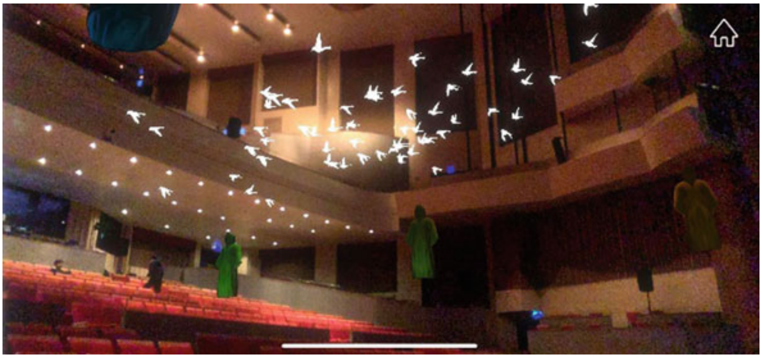


Fig. 5 Retention of virtual objects in space of performance hall

Fig. 6 Generate a fog after tapping

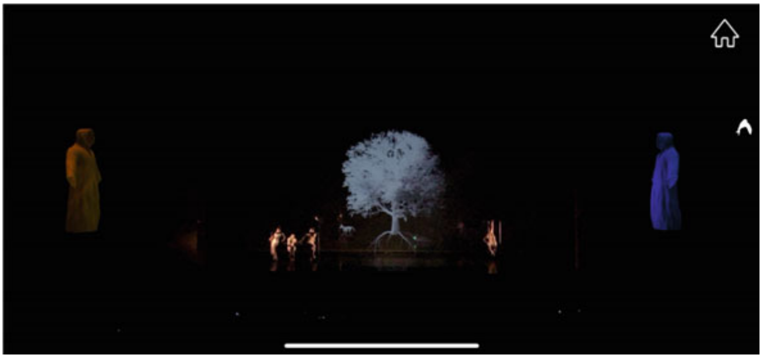


Fig. 7 Virtual objects gradually disappear

not indicate which tree to scan, using the same AR camera to scan the stage and marketing two different white trees would result in two different types of virtual content.

- Push notification function: It was originally planned that before the fifth act began, a push notification would be given to remind audience members to use their smartphones. However, considering the fact that some audience members may forget to turn their phones to vibration mode or that the flashing lights may affect other audience members, the push notification function was merely used during a set schedule before the beginning of the performance, reminding audience members to enter the performance hall, count down to the beginning of the performance, and provide various cautionary notices (Fig. 11).

Fig. 8 White tree used for marketing

Fig. 9 Promotional video on YouTube. Retrieved from https://youtu.be/wsiXUt8RwRM

2.3 Observation

The researchers observed on both performance days. All 600 tickets were sold out for both performances, and as the audience entered the performance hall, staff members at the door reminded them to scan the QR code to download the app (Fig. 12). The AR experience proceeded as follows:

- Audience members went to the Apple Store or Google Play to search for, download, and install the 'Epitome of Time' app.

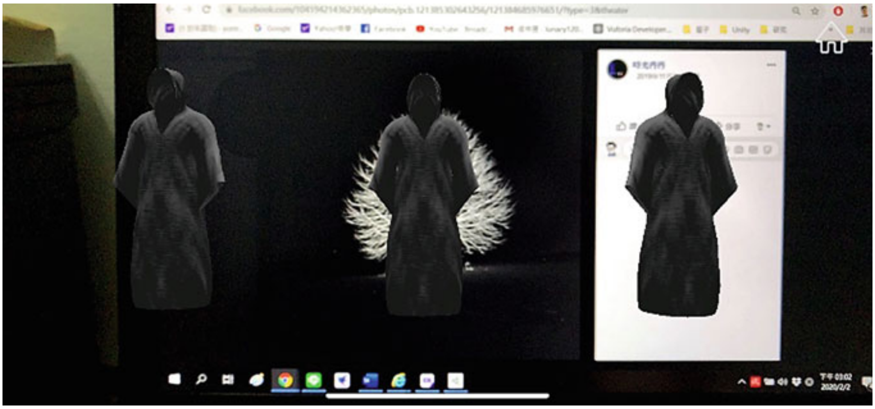


Fig. 10 Tapping virtual hooded figure producing discount code

Fig. 11 The push notification function

Fig. 12 Audience member scan the QR code to download the app

Fig. 13 Prompt on smartphone screen

- They tapped the AR camera to go into the AR camera mode. The phone screen then prompted audience members to scan the tree on the curtain (Fig. 13), which they proceeded to do (Fig. 14).

Fig. 14 Audience member using smartphone to scan projected image

Fig. 15 Objects displayed on smartphone screen after scanning of white tree

- After they aimed the AR camera at the image on the stage, virtual objects appeared in the space of the performance hall around them (Fig. 15). Audience members could tap on the virtual objects to generate other dynamic visual effects.

Data provided by Google Play and the Apple Store indicated that 217 downloads were made on Android and 402 downloads were made on iOS. Based on observations made by the researchers at the back of the performance halls during the performances, the responses of the audience members regarding the use of AR were as follows:

- Although many reminders had been given to audience members to take out their smartphones and scan the white tree when it was projected, many audience members were still not accustomed to doing so during the performance. For the most part, they focused on the performers on stage. Thus, the actual number of audience members that used the app during the performances was approximately 1/5 of the audience.
- Many of the virtual objects displayed on the phones of audience members drifted unsteadily.
- Most of the app downloads were made on the day of the performances. When the virtual objects appeared, many of the audience members, being first-time users, did not know that they could tap on the virtual objects.
- Audience members who were using the AR camera became focused on the virtual objects and neglected the performance on the stage.

After the performance, many audience members posted smartphone screenshots and comments on the social platform. Audience members said: "It is the first time in history to use smartphone to watch AR and the performance linked together. It is an amazing bonus scene.", "It is cool to experience AR in Epitome of time, audience members were very busy in this part. Pick up the phone, sometimes scanned the centre stage, sometimes scanned the left and right stage, and sometimes scanned the ceiling.", "Beautiful cross-disciplinary digital performance", "Epitome of Time, the performance lineup includes the cooperation of faculty and students from multiple departments. Audience members can download the app, which contains AR elements appear on the big tree aligned on the stage during the performance. It is a very contemporary performance!".

2.4 Reflection

Based on the research analysis results above, our suggestions for the use of AR on smartphones during performances are as follows: (1) In circumstances where the performance venue is not brightly lit, using a white scrim is best for AR positioning. (2) AR positioning is still likely to be unstable; if the virtual object used is too concrete, jittering and drifting can become even more obvious. Thus, abstract or particulate virtual objects would have better effects. (3) If AR is only using during a single act in the performance, it is suggested that staff members guide the audience in taking out their smartphones or remind them to do so. (4) In AR segments, the content should either stand alone or coordinate with the performance on stage; otherwise, it will shift the focus of the audience. (5) The sounds and lights of push notifications may disturb the audience during performances; thus, if push notifications cannot be incorporated into the performance content, they should be used for reminders and cautionary notices before or after the performance.

3 Conclusion

This study employed the action research method to create an AR app for a large-scale stage performance. By controlling the angle of their smartphone cameras, audience members could see virtual objects throughout the physical space of a performance hall that can accommodate over 600 people. The audience members could thus take part in the performance art and even directly interact with the content of the performance. The AR app can also serve as a way of marketing. This study was subject to the following limitations: (1) The hardware specifications of different smartphones vary, and it was difficult to take every one into account. (2) Although scanning by the audience derived identical results, there was no image synchronicity, mainly due to considerations regarding internet stability with so many people at the performance venue and the fact that it might affect the wireless equipment used in the performance. (3) We used the action research method for this case study, and the results are not representative for all large-scale performance art. However, this study proposes a method to incorporate smartphone AR into large-scale performance art, thereby providing reference for future applications. We believe that once 5G internet and various portable AR displays become popular, more visual interactive cyber-physical performance arts will become available to audiences.

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Testing Mixed Reality Experiences and Visitor's Behaviours in a Heritage Museum

Mariapina Trunfio, Timothy Jung, and Salvatore Campana

Abstract This paper aims to test the relationships between technological and functional, and experiential elements of the new realities, developing a conceptual framework based on (Trunfio and Campana, Current Issues in Tourism. 23(9):1053–1058, 2020) visitors' experience model for mixed reality in the museum to explore how mixed reality functional elements influence visitors' experiences in museum and post-experiences. Findings validate the influence of mixed reality functional elements on visitors' experiences, showing traditional experiences as a key museum experience to drive 4.0 experiences and post-experience behaviours. However, some theoretical questions remain open, considering the influence of usability requirements on interaction and 4.0 experience on museum post-experience.

Keywords Mixed reality · Smart technologies · Heritage museum · Visitors' interaction · Visitors' experience · Visitors' behaviour

1 Introduction

Mixed reality (MR) is a smart technological interface that combines virtual reality (VR) and augmented reality (AR) to integrate the processes of smart visualisation and immersion with advanced forms of the digital storytelling (Flavián, Ibáñez-sánchez, & Orús, 2019; Kang, Shin, & Ponto, 2020; Rahaman, Champion, & Bekele, 2019; Rokhsaritalemi, Sadeghi-Niaraki, & Choi, 2020; Trunfio, Campana, & Magnelli, 2020; Wang & Xia, 2019). It transforms the museum in a new multisensory and

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experiential space where the interaction between visitors and heritage exhibitions creates innovative forms of experiential value (Bekele, 2019; Fenu & Pittarello, 2018; Little, Bec, Moyle, & Patterson, 2020; Schaper, Santos, Malinverni, Zerbini Berro, & Pares, 2018).

Researchers focused attention on AR and VR covering diverse topics but in a fragmented way (Loureiro, Guerreiro, & Ali, 2020). Some studies analysed AR and VR functional elements and other readapted Pine and Gilmore's (1999) theoretical framework of experience economy to explore AR and VR effects (Kim, Lee, & Jung, 2020; Lee, Dieck, & Chung, 2020; Dieck, Jung, & Rauschnabel, 2018; Trunfio et al., 2020). The visitors' experience model for mixed reality in the museum (Trunfio & Campana, 2020) was proposed to measure how MR technological and functional elements impact on visitors' experience during heritage visits (seven dimensions, twenty-three items).

Although researches on MR explore both technological elements and visitors' experiences, how the MR technological and functional elements influence both visitors' experiences in museum and post-experience behaviours represent grey areas and spaces for future investigation.

2 Conceptual Framework

The paper aims to test the relationships between functional and experiential elements of the Trunfio and Campana's (2020) model (seven dimensions and twenty-three items), integrated with two visitors' experiential forms, traditional experience (heritage valorisation, and education) and 4.0 experience (entertainment, socialisation, and escape) (Trunfio et al., 2020) and visitors' behaviour effects (interest towards the new digital technologies, perceive the museum as unique, and promote a new visit to the museum). The conceptual framework is summarised in Fig. 1.

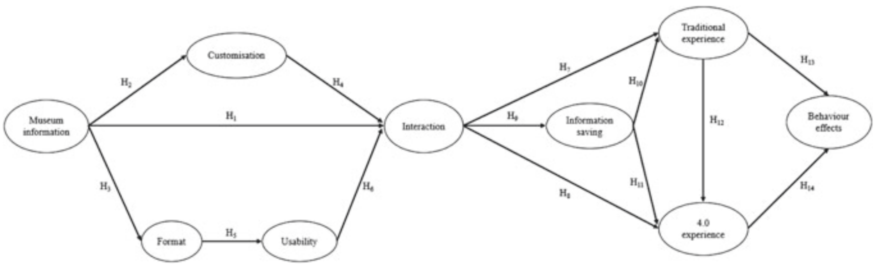

Fig. 1 Conceptual framework

2.1 The Relationship Between Museum Information, Interaction, Customisation, and Format

Traditionally museum visit identifies a direct visitors' interaction with the heritage exhibition, living a self-access to various museum information (Forrest, 2013; Poria, Biran, & Reichel, 2009). The new technologies have reinvented the interaction forms between visitors and heritage (Wang & Xia, 2019), improving the visualisation processes with customisation-information or immersion-information based on MR (Ardito, Buono, Desolda, & Matera, 2018; Fenu & Pittarello, 2018; Not & Petrelli, 2018; Trunfio et al., 2020).

H1: *Museum information has a positive effect on interaction.*

H2: *Museum information has a positive effect on customisation.*

H3: *Museum information has a positive effect on the format.*

2.2 The Relationship Between Customisation and Interaction

Visitors use customisation filters to visualise museum information in own language preferred, defining the access to specific museum information (Poria et al., 2009) that regard to the museum exhibition, services, historical period and city attraction (Trunfio & Campana, 2020; Trunfio et al., 2020).

H4: *Customisation has a positive effect on interaction.*

2.3 The Relationship Between Format and Usability

In contrast, MR integrates visualisation and immersion with interaction, combining audio, touch, video and image elements to promote correct museum information access (Bekele, Town, Pierdicca, Frontoni, & Malinverni, 2018; Flavián et al., 2019; Hudson, Matson-Barkat, Pallamin, & Jegou, 2019; Dieck, Jung, & Han, 2016; Trunfio et al., 2020). However, MR technical characteristics require a specific design in terms of complex hardware, software, and mobile computing (Bekele et al., 2018; Javornik, 2016).

H5: *Format has a positive effect on usability.*

2.4 The Relationship Between Usability and Interaction

MR stimulates visitors' interaction with the museum information (Trunfio et al., 2020). This circumstance occurs when MR respects the visitors' requirements of wearability or usability (Errichiello, Micera, Atzeni, & Del Chiappa, 2019; Dieck, Jung, & Dieck, 2018; Dieck et al., 2016), ensuring a comfortable design, easy-to-use and a clear identification about the access to museum information contents (Trunfio et al., 2020).

H6: *Usability has a positive effect on visitors' interaction.*

2.5 The Relationships Between Interaction, Traditional Experience, 4.0 Experience, and Information Saving

Interaction is a museum service critical aspect, allowing visitors to control their experience with the exhibition (Ardito et al., 2018; Antón, Camarero, & Garrido, 2018; Trunfio & Campana, 2020). Directly, visitors interact with the heritage exhibitions, deepening its contents with forms of traditional experience (heritage valorisation and education), or decide to use other immersive technologies to access at 4.0 experiences (entertainment, socialisation, and escape) (Ardito et al., 2018; Lee et al., 2020; tom Dieck et al., 2018; Trunfio et al., 2020). Indirectly, visitors save their interaction—on museum platforms or personal devices (Trunfio & Campana, 2020)—becoming an integrated part of digital storytelling (Hudson et al., 2019).

H7: *Interaction has a positive effect on the traditional experience.*

H8: *Interaction has a positive effect on experience 4.0.*

H9: *Interaction has a positive effect on information saving.*

2.6 The Relationships Between Information Saving, Traditional Experience, and 4.0 Experience

Information saving adds more value to visitors' experiences, creating digital souvenirs in terms of heritage homage (Bec, Moyle, Timms, Schaffer, Skavronskaya, & Little, 2019; Lee et al., 2020). It reinforces the visitors' social awareness about the heritage valorisation and preservation processes activated by the museum, becoming an attraction point for new and non-expert visitors (Bec et al., 2019; Little et al., 2020; Dieck & Jung, 2017; Trunfio et al., 2020).

H10: *Information saving has a positive effect on the traditional experience.*

H11: *Information saving has a positive effect on experience 4.0.*

2.7 The Relationship Between Traditional Experience and 4.0 Experience

Nowadays, museums use multiple technological interfaces to combine traditional experiences of heritage education and learning with advanced forms e.g. edutainment in which are presented characters of entertainment, socialisation, and escape (Addis, 2005; Antón et al., 2018; Trunfio et al., 2020).

H12: *Traditional experience has a positive effect on experience 4.0.*

2.8 The Relationships Between Traditional Experience, 4.0 Experience, and Visitors' Behaviours

By levering visitors' satisfying experiences, the museum becomes a tool to explore the visitors' future behaviours (Kim et al., 2020; Tussyadiah, Jung, & tom Dieck, 2018; Wei, Qi, & Zhang, 2019) in terms of interest towards the new digital technologies; perception of the museum as a place unique, original, and authentic; and how incentive to repeat the visit in the same or similar contexts (Kim et al., 2016; Wei et al., 2019).

H13: *Traditional experience has a positive effect on visitors' behaviours.*

H14: *Experience 4.0 has a positive effect on visitors' behaviours.*

3 Methodology

The empirical analysis interested an Italian heritage museum in which has been realised an important project of MR interface to increase visitors' experiential value. The project integrated AR and VR technologies enhancing visitors in immersive experiences.

A total of 312 data from visitors were collected using a self-administrated questionnaire. The questionnaire analysed two sections: the first section identified visitors' profiles (67% Italian and 37% International); the second section measured the nine constructs with twenty-six reflective multi-item by a seven-point Linkert-type scale (where 1 = strongly disagree, 7 = strongly agree).

A structural equation model (SEM) is used—considering the multivariate normality and linearity assumptions—to analyse the dependence among the observed constructs and their correspondent latent variables (Schreiber, Stage, King, Nora, & Barlow, 2006). Validity tests of the measurement model are conducted through a Confirmatory Factor Analysis and correspondent reliability. The analysis was performed using the maximum likelihood estimation method provided in LISREL 8 (Jöreskog & Sörbom, 1996).

4 Findings

The evaluation of the psychometric characteristics acquired considering the average variance extracted (AVE), composite reliability (CR), and Cronbach's alpha (α) on twenty-six items of nine constructs, overcome the recommended value of 0.50, 0.70, and 0.70 (MacKenzie, Podsakoff, & Jarvis, 2005) (Table 1). Considering the intra-

Table 1 CFA model

Constructs	Items	AVE	CR	α
Museum information	Exhibition	0.57	0.84	0.83
	Services			
	Historical period			
	City attraction			
Customisation	Personalised information	0.82	0.90	0.96
	Multiple language capability			
Format	Audio	0.66	0.88	0.89
	Images and video			
	Accessible using own mobile device			
	Touch			
Usability	Comfort	0.80	0.92	0.90
	Clever alternative to access information			
	Easy to use			
Interaction	Museum servicescape	0.69	0.87	0.87
	Multimedia elements			
	Other technologies			
Information saving	On museum platforms	0.85	0.92	0.92
	On personal devices			
Traditional experience	Heritage valorisation	0.63	0.77	0.76
	Educational			
4.0 experience	Entertainment	0.68	0.86	0.85
	Socialisation			
	Escape			
Behaviour effects	Increase interest in digital technologies	0.62	0.83	0.81
	Perceive the museum as unique			
	Promote a new visit to the museum			

Table 2 Correlation

		1	2	3	4	5	6	7	8	9
1	Museum information	1								
2	Customisation	0.14	1							
3	Format	0.19	0.03	1						
4	Usability	0.04	0.01	0.19	1					
5	Interaction	0.37	0.18	0.08	0.07	1				
6	Information saving	0.05	0.03	0.01	0.01	0.14	1			
7	Traditional experience	0.13	0.07	0.03	0.03	0.36	0.01	1		
8	4.0 experience	0.11	0.06	0.03	0.02	0.31	0.25	0.51	1	
9	Behaviour effects	0.04	0.02	0.01	0.01	0.12	0.08	0.30	0.21	1

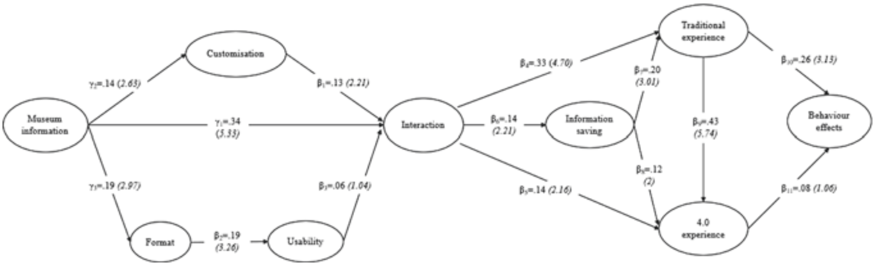

Fig. 2 Estimated results (t-value in parentheses)

correlations among constructs, the discriminant validity of the structure model is verified in all cases (Fornell & Larcker, 1981) (Table 2).

Global fits indicate a model with a good fit ($\chi 2 = 677.24$, d.f. = 285, $\chi 2$/d.f. = 2,37, GFI = 0.90, AGFI = 0.82, NFI = 0.90, NNFI = 0.93, CFI = 0.94, RMSEA = 0.067) (Jöreskog & Sörbom, 1996). Figure 2 shows the support of fourteen hypotheses (H1, H2, H3, H4, H5, H7, H8, H9, H10, H11, H12, and H13) and the rejection of two hypotheses (H6, and H14).

5 Conclusions, Research Implications and Limitations

The research tests the Trunfio and Campana's (2020) model to analyse the impact of visitors' behaviour effects under MR condition, identifying some preliminary theoretical and managerial implications that open future scenarios.

Firstly, the positive findings of reliability and global fits allow the theoretical and managerial validation of the Trunfio and Campana's (2020) model and test the hypotheses conceptualised (Trunfio et al., 2020). Future research should test the conceptual framework in various museum contexts to improve phenomenon comprehension.

Secondly, the H6 rejection shows how the MR usability requirements are still an important challenge for the museum that should provide interfaces with a more comfortable design and easy to use (Trunfio et al., 2020).

Thirdly, the rejection of H14 indicates how 4.0 experience is not significant in visitors' behaviour effects considering contexts of heritage museums with a high prevalence of heritage valorisation educational contents.

Some questions remain open about: What are the visitors' cultural differences that can influence the visitors' experience and behaviour under MR conditions? What are the other technological interfaces to promote alternative forms of visitors' visualisation and interaction?

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Interactive Mixed Reality Technology for Boosting the Level of Museum Engagement

Ramy Hammady and Minhua Ma

Abstract Holographic immersive technology such as 'Mixed Reality' is nowadays extending in the cultural heritage sector to open new prospects to engage visitors in museums. This paper investigates the level of engagement in the museum space by conducting observations and time consuming at the Egyptian Museum in Cairo. An interactive mixed reality system named 'MuseumEye' was developed and used Microsoft HoloLens as a mixed reality head mounted display to boost the level of engagement with the exhibited antiques. This system was experienced by 171 of the Egyptian museum visitors and another observation was conducted to record their behaviours and the time they consumed next to each antique. Results of this study showed the time consumed to engage with holographic visuals and the exhibited has been increased 4 times compared to the time the visitors consumed before without using technological gadgets. The implications of these immersive technologies can be an important vehicle for driving the tourism industries towards achieving successful engaging experiences.

Keywords Microsoft HoloLens · Engagement · Museums · Usability · Mixed reality · Observation

1 Introduction

Mixed Reality (MR) is trending the last few years on enhancing the museum engagement and the visiting experience when it incorporates with museum tours (Hou, 2019; Pollalis et al., 2018). Engagement is defined in different manners by different authors (Brodie, Ilic, Juric, & Hollebeek, 2013; Higgins & Scholer, 2009), such as attachment (Dwayne Ball & Tasaki, 1992), or emotional connection (Marci, 2006). Taheri,

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Jafari, and O'Gorman (2014) identified three drivers for engagement in tourism: prior knowledge, multiple motivations and cultural capital. Regarding engagement in museums, it enhances the visitors' consumption experience (Edmonds, Muller, & Connell, 2006). Normally, successful engagement is measured in museums by the average time spent in the space. However, the time may be consumed in other facilities in the museum such as the coffee shop (Falk & Storksdieck, 2005). Therefore, engagement for museum visitors is better represented in spending time with the interpretation techniques and creative presentations (Welsh, 2005).

HoloMuse as MR system impacted on boosting the level of engagement by incorporating interactive holographic in museums that can be manipulated by hand gestures (Pollalis, Fahnbulleh, Tynes, & Shaer, 2017). Other scholars used MR storytelling on the exhibits to engage visitors (Darzentas, Flintham, & Benford, 2018). Also, MR technology has been exploited to produce multiplayer games in museums to increase the engagement with co-visitors in museum spaces (Holloway-Attaway & Rouse, 2018). Many scholars attempted to engage visitors with the cutting-edge of MR systems and headset, however very few emphasised on providing an evidence of an actual impact these technologies on the museum engagement. This study employed a series of observation studies to provide metrics that can measure the level of engagement in museums specifically after adopting MR technologies. Also, this study built a new interactive holographic MR system using Microsoft HoloLens as a headset to boost the level of engagement at the Egyptian Museum in Cairo.

1.1 Pre-study

Based on a prior interview with one of the Cairo museum's curators, it was stated that either national or international museum visitors usually spend an average one hour in the museum, including roaming and touring. Based on the nature of the museum and its number of collections and rooms, this phenomenon was unusual as it also contradicts other studies that report that the average time spent in museums varies between 120 and 180 min (Chia, Yeong, Lee, & Ch'ng, 2016), and between 90 and 240 min in the Louvre museum (Yoshimura, Krebs, & Ratti, 2016). Many factors, can influence the time spent in museums such as economic, psychological, socio-demographic, trip-related factors (Brida, Nogare, & Scuderi, 2017), entry time, exhibits and number of visitors (Yoshimura et al., 2016). This research focuses on the time spent in front of the exhibited antiques and investigates how the visual experience and information was retained during the tour. A methodological exploration action was planned to take place due to the lack of essential information that the research could acquire from the literature review.

The prior observational studies used the approach of the random time sampling technique to capture the time consumed in the room of King Tutankhamun, which is located on the second level of the Egyptian museum. The observational study captured 20 participants of the daily museum visitors via a fixed camera fitted to different locations at different times. Visitors who observed where stood next to 4 different exhibits that belongs to the King Tut. The preliminary exploratory observation concluded that forty seconds was the average duration that visitors usually spend in the museum room without using guide tools or gadgets.

The average of the time spent is = (total spent time by sampled visitors) 812 ÷ (number of sampled visitors) 20 = 40 s.

This research adds to the snowballing body of evidence that MR technology can reshape and change the museum visitor's experience.

2 System Overview

In order to measure the influence of the MR technology on the touristic engagement levels, this research embarked to create an interactive holographic MR system using Microsoft HoloLens (Microsoft, 2015) as a holographic immersive headset that supports the mobility and hand gestures interactions for users on the spot of action. The system made to cover 10 antiques in the museum room.

2.1 Functionality

For the sake of fulfilling all visitors' needs and accomplishing the museum guide's objectives, a comprehensive list of functions—depicted in Table 1—was formed. Some functions were adopted from previous mobile guide studies that were suitable for the nature of the system. Also, several other new functions were built to exploit the device's abilities and achieve the aim of the system.

Museum professionals were involved in discussing the proposed functions in order to evaluate them with respect to different museum exhibits. Also, software developers were invited to discuss the possibility of the proposed functions from a technical perspective.

The system functions vary according to their classification, which can define the particular action that the visitor performs while using the system. The categories were tackled as per the below descriptions. Figure 1 demonstrates the functionality of MuseumEye next to the museum exhibits.

(1) Visual Communication: It is necessary to achieve direct communication between the visitor's senses and the system's visual and audio sources, as part of the immersive experience. So, a set of functions were designed to enrich the experience with various forms of communication during the tour such as spatial scenery, and animated avatars.

(2) Guidance: This involves a set of functions that involve visual and acoustical signs and cues, which guide the visitor around the museum room e.g. holographic labels, images, videos and interactive virtual replica of the authentic antique.

Table 1 List of MuseumEye functions

Functions/tasks	Description	Category	Purpose
Spatial scenery	It represents historical scenes composed of buildings, antiques and representations of characters—ancient Egyptian gods—considered to have spiritual power in ancient Egyptian culture. All of these virtual items will be mapped and superimposed on top of the physical room including ceiling, walls and floor	Visual communication	Make the visitor fully immersed in both realms
Storytelling by virtual guide performance	Stories or narrative content were synthesised from reliable sources. This content is animated and performed by the virtual guide who is the avatar of King Tutankhamun. The explanation is supplemented and synchronised by images which are augmented where the guide points The virtual Tutankhamun is life-size, and his way of acting is like as a human guide	Communication	Enrich the visitor with contextual information in an interesting manner Providing the visitor with a customised guide so the visitor can listen and watch the explanation
Script Text	A visible script in text format, to be triggered by the user	Guidance	It allows visitors to catch up with the ongoing explanation if part of it was missed. It provides an additional channel specifically for visitors with hearing loss

(continued)

Table 1 (continued)

Functions/tasks	Description	Category	Purpose
Images	Augmented images upon visitor hand interaction. These images represented the antique's condition when it was discovered. Moreover, these images were taken by the discoverer of the exhibited item	Guidance	Enrich the content with different layers of visual information. Moreover, most of these images are not available to visitors. Bringing these images while seeing the real antique is beneficial. It also exposes visitors to in-depth visual information if they are interested in more exploration
Audio narration	Audio commentaries by a narrator were produced from academic references in an interesting manner. They are synchronised with displayed images that are referred to in the commentaries for further clarification	Communication	This function is the essence of museum guidance, is to listen to a guide and look at the antique simultaneously. It provides an effective response to one of the patterns observed among visitors, namely the tendency to read labels with loud voices. Therefore, this function is built to ease the mission of reading to others aesthetically
Air tap/ Hand interactions	Interaction—by hand gestures such as air tapping- is possible in several ways: • Moving between scene • Reveal item's images • Reveal item's script text • Use the UI navigation buttons • Spin or rotate the virtual replica of the item	Interaction	Interactions can boost the level of engagement with visitors. As long as the user keeps interacting with the system, it means the information continues to feed into the user. Therefore, demanding information is a positive sign for knowledge retention

(continued)

Table 1 (continued)

Functions/tasks	Description	Category	Purpose
Knowledge scale game	It is an interactive game for discovering secret and thrilling information about each antique. Around each antique, there are small interactive circles, which reveal secret information next to them. It reveals this information by spinning the antique via hand gestures of the user's hands	Interaction	This educational interactive is designed to improve user engagement and information retention
Videos	An introductory and informative video about the museum collections and the particular collection exhibited is covered in the system	Guidance	Watching videos during the experience will add diversity to multimedia visuals. Videos have visual effects, text and images, created to be interesting for the visitor. Also, the visitor can skip the displayed video if he/she gets bored
Scenes portal points	Based on HoloLens' user location hotspots feature, MuseumEye provides interactive scene portals that are placed at key areas of interest. Once the user stands on top of it, it takes the visitor to the particular scene which is relevant to the item at that position	Guidance	It is a direct and physical way to access scenes that include the particular guided methods, relevant to each exhibited antique. It is also part of the multi-scenarios design of the tour
Orientation of Portal points	Auto-orientation occurs of the portal points that are capable of facing the visitor's position. Portal names will always face the visitor	Visual Communication	Auto-orientation of the text is a fundamental ergonomic aspect of the system. The title of the scene informs the user of the name of the exhibited item if the user is at a distance from the item. Besides, it provides access to the scene

(continued)

Table 1 (continued)

Functions/tasks	Description	Category	Purpose
Taking a photo / screenshot	The visitor can take a picture or screenshot of what he sees in MuseumEye using a voice command	Communication	This function allows the user to capture and share what he/she sees to others It is a response to the museum visitors' behaviour pattern, which was discovered in the pre-study observational analysis, namely the tendency to take photos
Collaborative shared experience	It allows a group of visitors who wear the HoloLens headsets to see what the single visitor can see. It is a collaborative experience, which means all interactions are also possible for co-visitors who are in the same network connection	Communication	This function encourages social interaction and opens prospects for open discussion between visitors. Hence, more interaction leads to gaining more knowledge about the context. This function was also built based on visitors' patterns explored in the pre-study, namely that visitors tend to walk in groups and have conversations next to the exhibited antiques
Animated characters	As part of the scene design, each character performs a particular animation to compose an epic and a harmonic glimpse of ancient Egyptian lifestyle	Visual Communication	This results in more influence on the sense of immersion in the mixed realms environment

(continued)

Table 1 (continued)

Functions/tasks	Description	Category	Purpose
Tap to Place portals	A hand gesture to interact with the scene portal and place them next to the relevant antiques. It is a protected function for museum curators who can access it through a combination of a keyword and hand gesture Also, 'tap to place' is utilised when the scene opens in front of the physical item. It gives the user the possibility to place the scene wherever he/she wants	Interaction	Working remotely with the museum guidance system was not easy to allocate the scene portals by the system creator. So, once the system creator places these portals in their right places, they will be allocated at these pointed forever. This function is also protected from the user but not protected for the museum curators if they want to change the exhibited items' locations. Once the user accesses these scene portals, they would see an entire scene with a set of visuals that can facilitate the needed guidance for the exhibited item
Interactive virtual replica of an original item	Large-scale replicas of the authentic exhibited items were created to display virtually next to the physical one. It is also interactive to explore the virtual replica from different angles and observe details that are not possible to perform in the real museum	Guidance / Interaction	To add partially the sense of controlling the object by 3D interaction as the user controls the authentic item. Hence, visitors can rotate and move the virtual replica as a sort of compensation for touching constraints that the visitor face towards the authentic one
User Interface (Navigation and Controls)	It is a wide and curved user interface that faces the user in the antique's scene, where the authentic item is placed next to the visitor	Interaction	The user interface provides the user with various types of controls that lead to the growth of the visitor's interactions skills. It also provides the user with the freedom to enter or leave the scene whenever he/she wants

Fig. 1 Participants are observed while using the MR museum guide—MuseumEye

(3) Interaction: This involves set of functions that utilise the headset's hand gestures to interact with spatial visuals. These functions aim to open up several ways of interaction between the visitor and the two realms; e.g. User interface (navigation and controls), interactive portals for each antique and knowledge scale game.

(4) Communication: This is essential to create lines of communication between the visitor and the virtual guide to transfer knowledge and give instructions, using audio and visual clues. These functions are such as; virtual storyteller of the King himself, audio narration, capture images and collaborative shared experience.

2.2 System Architecture

The MR system developments always be constructed by creating 2D and 3D assets and gesture interactions that can fulfil the designed functions.

The creation and development of the MuseumEye system took four stages as depicted in Fig. 2:

(1) *User Interface*: Designing the system's user interface requires the creation of UI design elements and UI interaction design.

(2) *Spatial Content Design*: This process involves creating the interactive portal points which were designed to be placed in front of the exhibited items to open interactive scene to the particular antique. Also, it includes the creation of the location design of holographic objects.

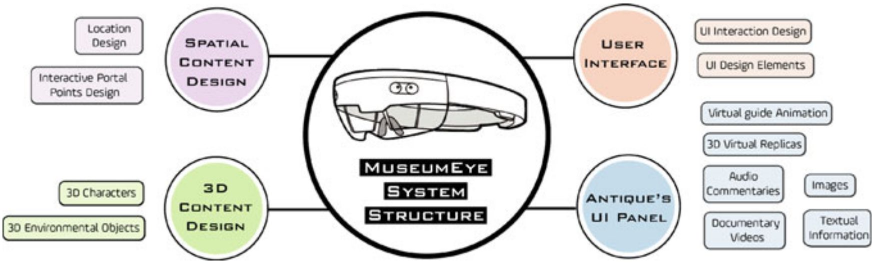

Fig. 2 MuseumEye content creation

Fig. 3 Participants are observed while using the MR museum guide—MuseumEye

(3) *Antique UI Panel*: This stage involves creating all visual communicative functions such as images, videos, and 3D holographic of the antiques' replica.

(4) *3D Content Design*: This stage includes creating 3D characters and 3D environment assets and all required assets for the narrative scenes.

We used Unity with HoloToolKit for developing the MR system with the 3D software packages such as Maya, zBrush and Substance Painter. Also, Microsoft Visual Studio has been adopted for deploying the application on the headset.

3 Method

The observation method has been frequently in museums to understand visitors' behaviours (Bollo & Dal Pozzolo, 2005; Lanir et al., 2017; Thrun et al., 1999). The observation method aims to record visitors' behaviours in the actual environment regarding the antiques exhibited. These behaviours include their movements, time spent next to/ in front of the antique, and how they react. The other aim of using observation is to conduct a critical comparison between the human behaviours in the current state of museum guidance and these same behaviours after applying the research solution. This comparison can visually demonstrate the differences in the engagement level and highlight the significance of using MR gadgets in museum tours.

171 of the daily museum visitors participated and observed in this experiment. This sample size was equal to the study conducted by Rubino, Xhembulla, Martina, Bottino, and Malnati (2013). Many museum studies relied on specific measurements to assess how people were attracted to exhibits such as *'Holding Power'* (Bollo & Dal Pozzolo, 2005; Hooper-Greenhill, 2006; Lanir et al., 2017; Serrell, 1997).

'*Holding Power'* is measured by calculating the total time spent in front of an exhibit, and is used to measure the visitor's interest. This measurement informs the preliminary idea of the power of an exhibit to hold the interest of a visitor (Bitgood, 2017) (Fig. 3).

4 Results

After observing the 171 participants during experimenting MuseumEye next to the targeted antiques, it was found that:

Time spent on exhibited items: the average time a visitor spent in front of each exhibited item was 177 s (**~=** 3 min).

In order to get the "Holding Power Index", the utilisation time necessary is needed to be defined. According to several interviews with experts and curators who work in this museum room, the antiques adopted for observation require from 1 to 2 min (90 s) as sufficient time to stay next to each of them for gazing and reading labels. This value represents the *'utilisation time necessary'*, which is required for the later observation analysis.

$$Holding\ Power\ index = \frac{Average\ stopping\ time}{Utilisation\ time\ necessary} = 177 \div 90 = 1.96$$

This measurement informs the preliminary idea of the power of an exhibit to hold the interest of a visitor (Bitgood, 2017).

As mentioned earlier, the preliminary observation studies measured the average of the time spent is 40 s.

$$Holding\ Power\ index = \frac{Average\ stopping\ time}{Utilisation\ time\ necessary} = 40 \div 90 = 0.4$$

The observation included the consuming of the content as the participant kept watching the virtual guide from 10 to 100 s, with an average of 36 s. Also, the spent from 1–8 min on the storytelling scenes with an average of 6 min.

The observation captured six different patterns on behaviours. The first pattern was that some participants seemed to be hesitant in using the MR system, especially with performing the hand interactions. Therefore, they asked for assistance during their tour. Regarding the second pattern, the observational camera and the written notes captured that some of the participants were smiling before, during or after their tour. The third pattern was that there were some participants who seemed familiar and confident with the system during the tour, as they did not ask for assistance and kept walking freely. The fourth pattern revealed a group of participants who had the same attitude of exploring the environment and keeping moving around themselves to discover the surrounding virtual world. The fifth pattern exposed a group of participants who accidentally faced crowds in front of their faces. This might obstruct the spatial visuals or cause issues with interactions' functionality, however, they seemed stable and engaged with the storytelling demonstrations. Furthermore, the sixth pattern represented a group of participants who were witnessed talking and smiling to their peers as they were trying to inform them what they could see.

5 Discussion and Conclusion

Time has been adopted as a robust and unobtrusive measure of museum visitors' attention (Falk, 1982; Serrell, 1995). The aim of designing MuseumEye and employing it in the Egyptian Museum in Cairo was achieved which extends the time that visitors spent in the museum. When comparing the results between the observation of the exploratory study and during the usage of the guide system, the Holding power increased from 0.4 to 1.96 respectively (from 40 s as an average to 177 s). According to Bollo and Dal Pozzolo (2005) *"The closer it is to 1, the greater the ability of the element to hold the visitors' attention will be"*. Therefore, the system was able to draw visitors' attention to the visuals seen around the exhibited antiques and the interaction they had to perform to gain more knowledge. Also, MuseumEye as a guide system can draw the attention of the three types of museum visitors: the greedy visitor, the selective visitor, and the busy visitor, which were categorised by Sparacino (2002).

Comparing the outcomes of the observation's statistics of this study with other studies that adopt technologies to extend visiting time, it was concluded that MuseumEye could extend the time much higher than other studies did. This study increased visiting time by 440% compared to the time visitors used to stay in the same room. When reviewing other studies, it was found that a study was conducted by Proctor and Tellis (2003), who were able to extend the time spent from 45 min using portable audio to 55 min using a multimedia tour pilot. Another study also extended the time from 49.6 min without using guides to 59.3 min with using a museum guide (Lanir, Kuflik, Dim, Wecker, & Stock, 2013). Moreover, an old study (Robinson, 1928) aimed to extend the time spent using a pamphlet guide, which increased from 17 min (unguided) to 28 min (guided). Another project could extend the spent time from 5 to 10 min using a mobile guide (Wang et al., 2009). A mobile application used to boost the engaging time in museums for students from—as an average—92 to 117 s compared with the usage of worksheets (Cahill et al., 2011). AR tools also has been used to expand the time of interacting and learning in museums from 133.28 to 206.74 s (Yoon & Wang, 2014). Another study calculated the time consumed by visitors who used the guidebook as it resulted 20,57 s compared to who did not use it which resulted 13.26 s.

If MuseumEye was adopted by the museum and scaled to include numerous collections of the museum antiques, visitors could spend many hours, which could result in days' worth of exploration, instead of approximately one hour in the regular visits.

5.1 Future Work

Based on the adopted approach, many activities can be held in museum rooms to boost the attraction levels in museums (Smith, Gomez, & Cortes-Rivera, 2019). Interactive holographic games can be designed to be played within the museum, based on quests that can be requested from visitors e.g. collect relevant relics or shooting historical villains.

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Immersive Technology Theories and Frameworks

Too Real for Comfort: Measuring Consumers' Augmented Reality Information Privacy Concerns

Lutz Lammerding, Tim Hilken, Dominik Mahr, and Jonas Heller

Abstract Privacy concerns are an often cited obstacle to consumer adoption of augmented reality (AR) technology, but research has not yet developed a specific measurement scale to capture these concerns. We address this need by drawing on AR and privacy literature to develop a ten-item Augmented Reality Information Privacy Concerns (ARIPC) scale. We follow a systematic scale development process that includes an empirical application of the scale. We offer novel and practically useful insights into consumer privacy concerns towards AR as a novel technology.

Keywords Augmented reality · Privacy concerns · Privacy calculus · Scale development

1 Introduction

Across a variety of contexts, firms increasingly deploy augmented reality (AR). For instance, IKEA's AR application enables consumers to virtually re-decorate their homes; Mister Spex' virtual mirror lets consumers 'try-on' sunglasses before buying online; and KabaQ's AR menus allow restaurants to showcase their food and drinks to consumers as lifelike 3D holograms (Jessen et al., 2020; Heller et al., 2019a; Hilken et al., 2017). AR's unique ability to project virtual content into the real world offers myriad benefits to consumers. For instance, in the context of frontline retail experiences, Heller et al. (2019a) show that AR outperforms traditional media due to its ability to make product or service experiences more vivid and easier to imagine; in the advertising context AR provides more informative and visually appealing content to consumers (de Ruyter et al., 2020); and in the online shopping context AR enables consumers to feel more comfortable with their purchase decisions (Hilken et al.,

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2017). However, despite these benefits, consumer adoption of AR remains slow, such that this novel technology might not live up to its widely-heralded potential. Indeed, only a small percentage of consumers consider adopting AR apps or find them worth recommending (Dacko, 2017; Rauschnabel et al., 2017; Rese et al., 2017). A recent study by the Boston Consulting Group (2018) also shows that only one-third of smartphone users in the US regularly use AR, while Gartner (2018) predicts that AR will be relevant for the consumer market in five to ten years at the earliest. This slow uptake is also a prominent motive for investors not to pursue business opportunities in the field of AR (Perkins Coie, 2019).

The reason for this stagnant development, in part, may lie in consumers' privacy concerns towards AR (Adilin, 2020). Major data leakages, cases of data misuse, cyber-attacks, and uncertainty about new technologies' abilities to violate individual privacy (e.g., Clearview AI) have sensitized consumers to information privacy. In a recent study, one-third of participants report privacy concerns towards AR and consider these as a major obstacle to using the technology (Dacko, 2017). This is hardly suprising, as AR requires consumers to point their cameras at themselves (e.g., Snapchat or Mister Spex) or their environment (e.g., IKEA Place or Pokémon Go) and thus reveal personal information, which they might not want to share. Thus, there is a pressing managerial need for more insights into AR-related privacy concerns, and particularly for assessing these with an easy-to-use measurement approach.

Research, however, has predominantly focused on privacy concerns towards specific AR devices (e.g., smart glasses; Rauschnabel et al., 2018) or relied on adaptations of early information privacy concern scales (Hilken et al., 2017), such that currently no AR-specific privacy concern scale exists. In general, many studies of privacy concerns towards new technologies utilize scales developed more than a decade ago (e.g., Smith et al., 1996; Malhotra et al., 2004). Yet, even the authors of these early scales themselves assert that measurement scales are "neither absolute nor static, since perceptions of advocates, consumers, and scholars could shift over time" (Smith et al., 1996, p. 190), thus stressing the transient validity of privacy scales. We thus believe it is crucial to develop a contemporary privacy concern scale for AR to gain insights into which factors might keep consumers from using this novel technology. Such a scale must consider both AR's unique features and the fact that consumers nowadays engage in a so-called privacy calculus, weighing the benefits and risks of use, before adopting new technology (Culnan & Armstrong, 1999; Martin & Murphy, 2017).

Following the call for more research on consumer privacy concerns (Martin & Murphy, 2017), we develop the Augmented Reality Information Privacy Concerns (ARIPC) scale. In doing so, we make three main contributions. First, drawing on privacy and AR literature, we identify a number of underlying dimensions for consumers' privacy concerns towards AR. These include both adaptions of established concerns (Collection, Transparency, and Control) as well as three novel AR-specific concerns (Unwanted Exposure, Bias Perception of Reality, and Contextualized Marketing). Furthermore, in line with social exchange (SE) theory and the notion of a privacy calculus, we propose a novel approach to measuring consumer privacy concerns by asking respondents to weigh the benefits against the privacy-related risks of using the technology. Second, we follow a systematic scale development approach to develop a ten-item ARIPC scale, which provides researchers and managers with an easy-to-use scale to measure AR-specific privacy concerns. Third, we offer an empirical application of the scale, showing that consumers' ARIPC negatively impact their cognitive and emotional engagement with AR as well as subsequent behavioural intentions (WOM and usage). In sum, this research offers much-needed insights into—and recommendations for managing—consumers' AR-related privacy concerns.

2 Theoretical Development

2.1 Existing Conceptualizations and Scales of Privacy Concerns

The complexity and contextual dependencies of the privacy concept have led to various definitions across time and contexts (Martin & Murphy, 2017). In this research, we focus on so-called information privacy, which is distinct from physical privacy and is defined as "the ability (i.e., capacity) of the individual to control personally […] information about one's self" (Stone et al., 1983, p. 460). AR applications typically scan and modify the consumer directly (e.g., virtual try-on of L'Oreal makeup), their surroundings (e.g., IKEA furniture holograms), or others within these surroundings (e.g., shared Snapchat filters). AR thus holds significant potential to cause concerns about personal information related to the self, surroundings, and bystanders, which motivates us to base our theorizing on this control-oriented definition of privacy.

The inherent contradiction between AR's reliance on personal information and the fact that consumers with privacy concerns do not see themselves in a position where they are in control of their information poses challenges. Malhotra et al. (2004) posit that the legitimate or illegitimate collection of personal data "is the starting point of various information privacy concerns" (Malhotra et al., 2004, p. 338). By evoking feelings of uncertainty and vulnerability (Barney & Hansen, 1994), information privacy concerns reduce the perceived trustworthiness of a technology and create psychological barriers to using it (Rauschnabel et al., 2018). This lack of trust has frequently inhibited consumer adoption of new technologies, thus prompting researchers to operationalize and measure consumer privacy concerns. The three most prominent measurement scales are: Concerns for Information Privacy (CFIP) by Smith et al. (1996); Internet Users' Information Privacy Concerns (IUIPC) by Malhotra et al. (2004); and Mobile Users' Information Privacy Concerns (MUIPC) by Xu et al. (2012). While all three scales have progressed insights into consumer privacy concerns about new technologies, they fall short in addressing the unique technological and social implications of AR. We thus use these scales as a starting point for our scale development of an AR-specific privacy concern scale.

2.2 Theoretical Foundations of the ARIPC Scale

To explore consumers' information privacy concerns towards AR, we conducted a semi-structured focus group interview with six graduate business students from a Dutch university. We introduced participants to AR and let them familiarize themselves with various applications (i.e., IKEA Place app, L'Oréal and Mr. Spex virtual mirrors). Participants then answered questions about their experience, concerns, and intentions regarding AR. We encouraged participants to directly respond to their peers' remarks to reveal both points of consensus and disagreement. The session was recorded and independently transcribed by two researchers. The findings revealed that today's consumers have resigned from the illusion of being in control of their data. Participants agreed that trying to conceal personal information may be ineffective due to the manifold data-gathering techniques. Most importantly, participants also reported that experiencing the benefits of new technologies without sacrificing information privacy is likely not possible in today's digitally connected world. This behavioural contradiction, called the "personalisation/privacy paradox", has received increasing attention in the literature (Aguirre et al., 2015), and is based on the human tendency to heavily discount future events (i.e., costs of giving up personal data) and to focus on immediate benefits (i.e., reward one gets in exchange for a piece of information). As a result, although consumers are concerned about their privacy, they willingly provide their personal information to companies, for example, when the benefits of data-intensive applications seem to outweigh the risks (Smith et al., 2011). Participants also reported that they base their decision, whether to use AR or not, on the related costs and benefits. While data provision is seen as a cost, the visualization of products in the users' surroundings when using AR is considered as the main benefit.

Social exchange (SE) theory explains the rules for the bilateral exchange of resources, which are thought to provide benefits to the exchange partner (White, 2004). SE theory has thus proven particularly useful in investigating relationships based on costs and benefits as perceived by consumers (Martin & Murphy, 2017). The parties involved in an exchange aim to maximize benefits and only provide resources (i.e., they only incur costs) when they expect a net gain (White, 2004). Thus, in the context of information privacy, consumers are willing to participate in a social exchange by revealing personal information if the perceived benefits exceed, or at least compensate for, the perceived costs (Culnan & Armstrong, 1999; Martin & Murphy, 2017).

In the context of AR, SE theory suggests that the exchange is only balanced, when the benefits of using AR, such as the ability to customise (Carrozzi et al., 2019) or creatively engage (Jessen et al., 2020) with products and facilitate decision making (Hilken et al., 2020), outweigh the various costs and risks of giving up personal information, leading consumers to act contrary to their information privacy concerns. The aggregated costs consumers associate with AR use are the AR-specific privacy concerns, which we seek to measure in this research. The social exchange is imbalanced when a company harms the consumer by violating the reciprocity, increasing the individuals' costs, and its own benefits. Culnan and Armstrong (1999) label the rational assessment of costs and benefits regarding the disclosure of personal information as a transaction privacy calculus. Therefore, we design the ARIPC scale in a way that captures the AR cost-benefit trade-off, providing companies with the means to measure which particular privacy concerns outweigh the benefits, and, in turn, would lead consumers to not use the technology.

2.3 Dimensions of the ARIPC Scale

On the basis of our review of existing scales in the literature, enriched by the insights from the focus group interview and the theoretical foundation of SE theory, we identify seven potential dimensions for the ARIPC scale. Four dimensions are captured by existing scales: Collection, Transparency, and Control from the IUIPC scale by Malhotra et al. (2004), and Perceived Surveillance from the MUIPC scale by Xu et al. (2012). In addition we propose the following three AR-specific dimensions.

First, *Unwanted (Social/Economic) Exposure* captures consumers' concerns about being exposed due to their use of AR. Feelings of vulnerability are fostered not only because of the information consumers reveal about themselves when using AR, but also because of the implicit information and interpretations about their social and economic background that can be drawn based upon this information. Therefore, this ARIPC dimension goes beyond the MUIPC's dimension of Perceived Intrusion (Xu et al., 2012). For instance, users of the IKEA Place app might not feel comfortable with revealing their taste in furniture because it could be labelled as embarrassing in their social reference group (i.e., Unwanted Social Exposure); they might also not want other people to interpret their economic situation based on the prices of virtual furniture they choose (i.e., Unwanted Economic Exposure).

Second, as AR digitally transforms the real world by projecting virtual content into the physical environment, consumers could be concerned about a biasing effect on their perception of reality (i.e., *Perception Bias of Reality*). Prior research has demonstrated that AR can shift the perceptions of users about their own appearance or body image (Yim & Park, 2019). This effect is illustrated by beauty-enhancing Snapchat filters, which have recently gained media attention surrounding the phenomenon of "Snapchat Dysmorphia" (The Guardian, 2019), where the criteria of a person's beauty perception experiences a shift towards the ideals of beauty promoted by face-filters when regularly confronted with them. The logic can easily be extended to consumer concerns about AR applications altering their physical environment, for instance by displaying only certain (branded) products or biasing their decision making with by visually enhancing certain information in the real world.

Third, *Contextualized Marketing* addresses consumers' concerns about the potential extraction of personal information from their use of AR and subsequent information processing for targeted marketing purposes. After all, AR applications rely on visual detection features that scan the consumer or their environment (Chylinski et al., 2020), and they also track which AR-content a consumer has viewed—both of which can provide marketers with novel personalised marketing opportunities. On the one hand, literature labels targeted advertising and marketing communication as costs that are inherent to using a service. On the other hand, personalized marketing offerings, when perceived as valuable to the consumer, are considered benefits (Martin & Murphy, 2017), indicating the delicate balancing act that results from data collection and personalization. In the scope of this research, information is considered AR-specific when it combines information collected from the various features of AR (i.e., time- and location-based services, scanning the environment or oneself, augmenting digital content into the real world) into a new source of information. For instance, choosing a particular face filter on Snapchat more often than others could be an indication of a user's beauty ideals. In turn, this information could be used to promote products or services designed to address the consumer's (implicit) needs and wants.

3 Methods

To systematically develop a valid and reliable ARIPC measure, we employed a staged process based on fundamental guidelines (Churchill, 1979) and contemporary procedures (Kiratli et al., 2016; Yim et al., 2018) for scale development.

3.1 Item Generation and Refinement

We first reviewed AR and information privacy literature, including existing privacy concern scales, to generate an initial pool of 23 items. We then presented these items to the participants in our focus group interview, who confirmed the relevance of these initial items and offered us with insights to formulate six new items. Participants also verified the need for incorporating a privacy calculus into the scale. We thus anchored the items at 1 = "benefit strongly outweighs the concern" and 7 = "concern strongly outweighs the benefit". Based on the insights gained through the focus group, a subsequent panel discussion amongst the authors expanded the item pool to 40 items. An independent AR expert from a Dutch university then reviewed these items for content and face validity, resulting in minor improvements in the wording.

3.2 Exploratory and Confirmatory Factor Analyses

We incorporated the 40-item scale into an online study, which was completed by 162 participants (98 women and 64 men, aged 19–65). The sample included 74 students from a Dutch university participating in exchange for course credit and 88 consumers who responded to our posting of the study on social media. Participants read an introduction to AR, then used either an AR mirror (Mister Spex) to virtually try on sunglasses or an AR retail application (Onirix) to preview home appliances. They then rated the ARIPC items, in addition to their cognitive ($\alpha = .88$) and emotional ($\alpha = .93$) engagement with the AR experience on adapted three-item scales by Hollebeek et al. (2014) as well as their AR-related WOM ($\alpha = .93$) and usage ($\alpha = .94$) intentions on adapted three-item scales by Zeithaml et al. (1996) and Hilken et al. (2020).

We conducted an EFA with principal axis factoring and direct oblimin rotation on the 40 ARIPC items. The correlation matrix revealed excessive correlation ($r = .92$) between two items, so we removed one of these items. A Kaiser-Meyer-Olkin value of .94 (Kaiser & Rice, 1974) and Bartlett's (1954) test of sphericity ($p < .001$, χ^2 (df) = 6460.01 (741)) supported the suitability of the data for factor analysis. Kaiser's (1960) criterion for retaining factors with eigenvalues greater than one suggested a five-factor solution explaining 71.9% of the total variance. However, the scree plot revealed the possibility of a three-factor solution, which, as our subsequent analyses revealed, explained a comparable amount of the total variance (65.1%) as the five-factor solution despite the lower number of items. We thus continued with the more parsimonious three-factor solution. We dropped items with low loadings (<.45) and communalities below .4 in an iterative process (Hair et al., 2010), which resulted in a final set of 10 items. A second EFA on these items revealed a three-factor solution explaining 79.03% of the total variance (Table 1). Each of the items loaded onto its intended factor, such that the final scale included four items related to *Unwanted Exposure (UnEx)*, two items measuring *Perception Bias of Reality (RB)*, and four items for *Contextualized Marketing (CM)*. The three subscales all exhibited good internal consistency ($\alpha > .7$; DeVellis, 2017).

Next, we used AMOS 26 to perform a CFA with the three previously identified factors as indicators of a higher-order ARIPC construct. We found good model fit overall (GFI = .894, AGFI = .817, CFI = .937, TLI = .912), but also a relatively high RMSEA (.113) that exceeded the threshold of 0.08 as well as a significant chi-square test ($\chi^2 = 114.976$; $p < .001$) indicating poor model fit (Hair et al., 2010). We reflect on these results in our limitations. As shown in Table 2, the composite reliability values for each construct exceeded the cut-off value of .7 (Hair et al., 2010). We also found support for convergent validity, as each item contributed ($p < .01$) to the measurement of its factor with loadings above .7. Furthermore, the R^2 values of each item exceeded the threshold of .3 and the AVE exceeded 50% for each factor (Hair et al., 2010). We also established discriminant validity, as the square root of each construct's AVE was exceeded its correlation with the other factors (Fornell & Larcker, 1981).

Table 1 ARIPC items and EFA results

Item	UnEx	RB	CM
UnEx1. It bothers me that I unintentionally give too much information about my personal economic situation, as can be derived from the quality of my AR output	**.962**	.011	.090
UnEx2. It bothers me that the combinations of my real surroundings and the virtual layers/content I choose to apply may provide interpretable information about my social status to others	**.869**	.023	.057
UnEx3. It bothers me that others might find out more about my personal preferences than I am comfortable with as a result of using AR to combine my real surroundings with digital content.	**.750**	.090	−.123
UnEx4. I am concerned that as a result of using AR, others might know more about my personal surroundings, people in my environment, or myself than I am comfortable with	**.700**	−.043	−.020
RB1. I am concerned that AR applications might bias how I evaluate the attractiveness of objects or other people, form preferences, or make decisions without me noticing, for instance, about which products or services to buy	.002	**.939**	.021
RB2. I am concerned that AR applications might bias how I see my environment or myself without me noticing	.052	**.771**	−.055
CM1. It bothers me how companies use the data that AR applications collect about the digital content that I see projected onto myself or into my environment	.060	−.140	**.901**
CM2. I am concerned that companies use the data that AR applications collect to target me with advertising related to the products I have tried out in my environment or tried on for myself by using AR	−.021	.102	**.742**
CM3. It would bother me if companies use the data collected by AR applications to provide product or service suggestions based on what I look at or what I look like	−.065	.090	**.723**
CM4. I am concerned that I do not have full control over the way companies use the data that AR applications collect about the digital content that I see projected into my environment or onto myself	.134	.003	**.722**
Eigenvalue	5.271	1.346	1.286
Percentage of variance explained	52.712	13.45	12.859
Cronbach's α	.914	.864	.867

3.3 Nomological Validity and Empirical Application

We sought to offer an empirical application and test the nomological validity of the ARIPC scale by establishing its relationship with related concepts. Specifically, we tested whether a consumer's ARIPC predict cognitive and emotional engagement with an AR experience, and, in turn, their AR-related WOM and future usage intentions. This sequence of effects is based on recent theorizing of how consumers engage with AR and adopt it as a new technology (Heller et al., 2021). Using participants'

Table 2 CFA results

Construct	1.	2.	3.	R^2	CR	AVE
1. Unwanted exposure	**.857**				.917	.734
UnEX1	.865			.748		
UnEX2	.899			.808		
UnEX3	.795			.632		
UnEX4	.865			.749		
2. Perception bias of reality	*.454*	**.844**			.831	.712
RB1		.892		.795		
RB2		.793		.628		
3. Contextualized marketing	*.604*	*.464*	**.876**		.876	.641
CM1			.837	.700		
CM2			.877	.769		
CM3			.753	.567		
CM4			.725	.526		

Notes CR Composite Reliability, *AVE* Average Variance Extracted. The square root of the average variance extracted is shown in boldface. Factor correlations are shown in italics

ratings of these measures from our study, we followed an approach similar to that of Yim et al. (2018) by collapsing all 10 ARIPC items into a single measure (α = .87) and then using the PROCESS macro (Model 4) to test the *ARIPC* → *cognitive /emotional engagement* → *WOM /usage intentions* mediation pathways. The results of our analyses are in Table 3. As expected, consumers' ARIPC negatively impacted their emotional and cognitive engagement with the AR experience. In turn, emotional and cognitive engagement shaped both WOM and future usage intentions. A bootstrapping procedure with 5,000 samples and bias-corrected confidence intervals (CIs) revealed significant negative indirect effects for all pathways as the CIs excluded zero (Table 3), thus supporting the overall nomological validity of the ARIPC scale.

4 Discussion and Conclusion

We address the need for a measure of consumers' AR-related privacy concerns by developing the ten-item ARIPC scale that is based on a privacy calculus for weighing the benefits and risks of using AR. Notably, this scale is comprised of three novel AR-specific privacy dimensions (Unwanted Exposure, Perception Bias of Reality, and Contextualized Marketing), while established privacy dimensions (Control, Transparency, Collection, and Perceived Surveillance) appear to not adequately describe consumers' privacy concerns towards AR. By demonstrating

Table 3 Regression results

Variables	Emotional engagement	Cognitive engagement	WOM intentions	Usage intentions
Intercept	6.15 (.31)**	4.743 (.40)**	.929 (.59)	1.295 (.68)
ARIPIC	−.474 (.07)**	−.214 (.10)*	−.056 (.10)	−.182 (.09)
Emotional engagement			.536 (.08)**	.272 (.09)**
Cognitive engagement			.300 (.06)**	.466 (.07)**
R^2 (MSE)	.205 (1.345)	.029 (2.328)	.428 (1.309)	.362 (1.766)
F	41.363**	4.846*	39.450**	29.827**
df	1, 160	1, 160	3, 158	3, 158
Indirect effects		Effect	Boot SE	Boot CI
ARIPC → emotional engagement → WOM		−.254	.061	−.37 to −.14
ARIPC → emotional engagement → Usage		−.129	.049	−.23 to −.04
ARIPC → cognitive engagement → WOM		−.064	.033	−.13 to −.00
ARIPC → cognitive engagement → Usage		−.100	.049	−.20 to −.01

Notes The numbers in parentheses are standard errors. Unstandardized coefficients are shown. Significance based on two-tailed test. ** $p < 01$. * $p < .05$

that consumers' ARIPC negatively impact their engagement and behavioural intentions, we also provide evidence for the scale's predictive power and substantiate the importance of addressing privacy concerns for mainstream adoption of AR as a new technology.

4.1 Implications for Theory

We contribute to extant AR literature in three ways. First, because of consumer backlash against early AR platforms (e.g., Google Glass), researchers have predominantly studied privacy concerns towards wearable AR devices, most notably AR smart glasses. Such privacy concerns, however, are hardware-specific and mainly relate to wearing smart glasses in public and potentially inferring with other consumers' privacy (Rauschnabel et al., 2018). In contrast, we develop a general-purpose scale that can be assessed independent of any specific AR device. Second, previous studies (e.g., Hilken et al., 2017) have largely relied on adaptations of existing privacy concern scales, such as the IUIPC (Malhotra et al., 2004), which were designed more than a decade ago in an entirely different technological and societal context.

Our findings emphasize the need for an update in the measurement of customer privacy concerns: Unwanted Exposure, Perception Bias of Reality, and Contextualized Marketing are novel and AR-specific dimensions that explain significant variance beyond well-established privacy concerns. Third, the ARIPC scale not only accounts for AR's novel technological characteristics, but also the now common practice of engaging in a privacy calculus before using a new technology. Stimulating consumers to assess their privacy concerns through a privacy calculus is an innovative approach, and, to the best of our knowledge, the ARIPC scale is one of the first attempts at implementing this calculus within a psychometric measure.

4.2 Implications for Practice

Our findings also offer a number of implications for practitioners seeking to deploy AR to enhance their interactions with consumers. First, as consumers' ARIPC negatively impact their engagement with AR, practitioners should increase their efforts to decrease privacy concerns when using AR. Second and relatedly, the ARIPC scale offers insights into what consumers are concerned about when using AR technology, which offers specific guidelines for practitioners. That is, allaying fears about unwanted social or economic exposure, a biased perception of reality, and contextualized marketing should be at the topic of managers' and developers' agendas when designing AR applications. For instance, assuring potential users of an AR application that their data will not be used for marketing purposes might be effective in reducing privacy concerns and stimulating engagement with using the app. Third, because consumers often do not automatically follow through on their intentions to use a new technology, reinforcing consumer-to-consumer WOM is particularly vital to the mainstream adoption of new technologies. The results of our nomological testing reveal that the negative effect of customers' ARIPC on WOM is mainly driven by lower emotional engagement. Practitioners should thus not only consider the design and functionality of AR applications, but also deploy AR at the right time in the consumers' purchase journey to alleviate customer pain points and associated negative emotions (Hilken et al., 2018)

4.3 Limitations and Future Research

We acknowledge some limitations that offer opportunities for further research. First, there was some ambiguity in the goodness-of-fit measures within our CFA. Although, according to Hair et al. (2010), this is not unusual as no index can differentiate good from poor models in all contexts, the validity of the ARIPC should be further evaluated. Second, while we sampled a diverse set of consumers, the majority of participants can be considered early adopters of new technologies (with an average age of 26.96). Further testing of the ARIPC, particularly in late-adopter segments would enhance the generalizability and help identify boundaries of the scale's application. Third, while behavioural intentions offer important first insights into the nomological validity of the scale, future research should investigate the effect of consumers' ARIPC on their actual behaviour (e.g., purchase choices, app usage behaviour, social media likes/posts). Fourth, while the ARIPC appears valid across two major types of AR applications (enhancing the self, enhancing the environment), an update of the scale might become necessary the technology evolves to include more social (Hilken et al., 2020), multisensory (Heller et al., 2019b), or AI-enabled features (Chylinski et al., 2020).

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The Proteus Effect: How Avatars Influence Their Users' Self-perception and Behaviour

Anna Samira Praetorius and Daniel Görlich

Abstract The Proteus Effect, introduced by Yee and Bailenson (2007), suggests that users of a virtual environment adapt their behaviour to the characteristics of their respective avatars. Because numerous studies and experiments concerning the Proteus Effect have been published since 2007, we herein provide a literature review and evaluate the theoretical framework. Based on the comparison of their findings and conclusions about the theoretical framework of the effect and its explanatory approaches such as self-perception theory and priming, we classify these studies with regard to self-similarity, wishful identification, and embodied presence. This allows for revealing parallels to the processes of self-identification.

Keywords Proteus effect · Virtual environments · User behaviour

1 Introduction

By way of an avatar, users can slip into a variety of alternative identities, independent of their own identity in the "real world". Resembling the real self is not a prerequisite for a user's identification with their avatar. Just as the authentic self is not a fixed, monolithic entity, the perception of the virtual self is also constructed (Hamilton, 2009). But does experiencing alternative forms of the self also influence the authentic self in return?

The effects of avatars on their users have not yet been sufficiently researched, although the observation that individuals change their behaviour to conform to their digital self-representations was introduced and named the "Proteus Effect" as early as 2007: Yee and Bailenson (2007) named this effect after Proteus, the Greek deity who had the ability to take on the form of any being and even of inanimate structures

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such as water or fire. Continuing previous research on immersive virtual environment technology as a methodological tool for social psychology (Blascovich et al., 2002) and interpersonal distance in immersive virtual environments (Bailenson et al., 2003), they conducted experiments where they assigned users different avatars and observed their behaviour. They found that the subjects changed their behaviour to conform to their digital self-representation and to the behaviour they believed others would expect them to have, even when they did not receive any behavioural confirmation (Yee & Bailenson, 2007). To date, the exact mechanisms behind this effect are unknown. There are several explanatory approaches, especially ones focusing on self-perception theory and others focusing on priming. As a foundation for further research, we carried out a thorough literature review of studies and experiments focusing on the Proteus Effect, identifying publications and results that support or contradict the Proteus Effect, and pinpoint research gaps. Based on the review and comparison of studies regarding the Proteus Effect, their findings and conclusions about the theoretical framework of the effect and its explanatory approaches, we classify these studies with regard to self-similarity, wishful identification, and embodied presence. This allows us to reveal parallels to the process of self-identification.

2 State of the Art

Self-perception Theory According to self-perception theory, people derive identity cues and attitudes from their analysis of their own past behaviour and circumstances (Bem, 1967). This happens whenever there is uncertainty about one's own feelings and attitudes and can lead to self-attribution. The basic assumption is that there is no fundamental difference in the way people interpret their own and other people's behaviour. This means that just as it is possible to draw conclusions about the attitudes and desires of other people by observing them, one's own behaviour can also be observed in order to gain insight into the behaviour others would expect.

Classic Deindividuation Theory According to Aronson et al. (2011), classical deindividuation theory assumes that in group situations there is an increase in impulsive actions that deviate from the norm. This happens because the individual is lost in the anonymity of the masses and the fear of being judged negatively decreases. Deindividuation happens when individual identity recedes into the background, which can lead to weakened behavioural control and even violent behaviour. The idea that dehumanisation takes place and that the potential for aggression increases in the masses is no longer represented in the newer SIDE model (Reicher et al., 1995).

SIDE Model According to Reicher et al. (1995) the SIDE model (Social Identity Model of Deindividuation Effects), assumes that deindividuation is a depersonalisation in the sense of a process of self-categorisation, thereby challenging classical deindividuation theory. In group situations, a suppression of personal identity in favour of the respective group norm can occur. Depending on the social and situational circumstances, the self thus categorises itself according to group membership.

A person defines himself/herself less through individual aspects and instead through the group surrounding him/her, because social identity and the categories of the group are salient.

Priming According to Bargh et al. (1996), the automatic activation of implicit memory contents, which then leads to an influence on the processing of subsequent stimuli, is called priming. If a stimulus is salient, this sets in motion an unconscious process and determines how concepts are retrieved and interpreted in the situational context, which can also guide perception, attitude, and behaviour. In social exchange, stereotypes in particular are common categories that are automatically activated when physical features are present that are associated with a particular social group.

Stereotypes According to Cesario et al. (2006) stereotypes play a major role in the assessment of other people. Stereotypes are associations that ensure that certain characteristics and traits are attributed to a group of people. These influence how the corresponding counterpart is perceived and evaluated, which ultimately also determines one's own behaviour towards the person. Not only is the behaviour of the stereotyping person a consequence of the stereotyping, it can also happen that a person elevates their own qualities and behaviours to a stereotype by self-categorisation and acts accordingly (Sommer, 2017). Furthermore, the behaviour that the stereotyping person shows towards the stereotyped person can lead to the fulfilment of the stereotype expectation.

Avatars and Virtual Embodiment Yee and Bailenson (2007) present the Proteus Effect by name for the first time and show that attractive avatars increase self-disclosure and large avatars lead to more confidence, even if behavioural confirmation is excluded. These experiments are conducted with head-mounted displays in an immersive virtual environment. Yee et al. (2009) extend these results in a follow-up study and examine the Proteus Effect using the example of an online gaming community. In this case a third-person desktop application is used. It is shown that the results are reproducible and that large, attractive avatars lead to the best game performance outside of a laboratory setting. The other experiment takes place in an immersive virtual environment with HMDs and repeats a scenario from the first study by Yee and Bailenson (2007). They show that a Proteus Effect is upheld even after leaving the immersive virtual environment.

The first study which raises criticism of the attribution of the Proteus Effect to self-perception theory is published by Peña et al. (2009). Their experiments are conducted in a desktop environment and from a third-person perspective. They show that black-clad avatars lead to more aggressive behaviour than white-clad avatars and attribute the Proteus Effect to priming as an alternative explanation. Yee and Bailenson (2009) argue that the results of Peña et al. (2009) may be attributed to the fact that only a desktop environment and the third-person perspective is used, whereas in the sense of the self-perception theory embodiment is of particular relevance. Accordingly, Yee and Bailenson (2009) investigate the difference between being and seeing by comparing immersive and non-immersive environments. While one group of the test subjects experiences a scenario with HMDs, the other group sees the same visual stimulus on a screen as a playback. They classify the exclusive observation of the visual stimulus as a priming component and embodiment in the immersive environment as a self-perception component. In this experiment, a Proteus Effect can be observed only after embodiment in the immersive virtual environment. In another study by Yee et al. (2011), however, a Proteus Effect is observed in a desktop environment when investigating behaviour in an online gaming community with a third-person perspective. They show that male avatars tend to seek combat and female avatars tend to act as healers, which indicates that virtual identity cues may take precedence over physical features. However, this study concedes that behavioural confirmation may also play a role, which was not excluded as it was in the earlier study by Yee and Bailenson (2007).

A study by Fox et al. (2012) takes place in a fully immersive virtual environment experienced through an HMD. Here a Proteus Effect can be clearly confirmed, as they find a connection between the Proteus Effect and self-objectification when women embody a sexualised avatar. In the same year, a study by van der Heide et al. (2012) shows that behavioural compensation can counteract the Proteus Effect and that unattractive avatars can lead to more relational closeness than attractive avatars. However, this study again takes place in a desktop environment and the test subjects only see their avatar as an image during an online chat. The same applies to the study by Sherrick et al. (2014) who only use images of the avatar parallel to an interactive story in a desktop environment and cannot observe a Proteus Effect. They also consider behavioural compensation to be a potential reason why their results do not conform with the predictions of the Proteus Effect, and female/male avatars do not lead to stereotypically feminine/masculine decisions. In a study by Lee et al. (2014) the avatars are merely images as well, yet a Proteus Effect can be confirmed: They show that gender stereotypes can be transferred to virtual competitive situations and can influence cognition, so that male avatars can lead to better results when solving a mathematical task. It is also shown that stereotypes can be of particular relevance for the Proteus Effect and that the occurrence of stereotype threat and stereotype lift effects can serve as indicators for the Proteus Effect.

A study by Bian et al. (2015) takes place in a third-person perspective desktop environment. They show that the attractiveness of the avatar can cause individual shyness to recede when initiating interaction, but in the continuation of interaction, where social skills are required, internal characteristics such as shyness predominate and no Proteus Effect due to attractiveness occurs. However, a study by Guegan et al. (2016) which likewise takes place in a third-person desktop environment, demonstrates a positive influence of the Proteus Effect on creativity inside and outside the virtual environment by using inventor avatars. The researchers consider both self-perception theory and priming to be plausible explanations, but do not commit themselves. A study by Ash (2016) also investigates the relationship between priming and the Proteus Effect. The experiment takes place on a screen from a third-person perspective and no Proteus Effect can be determined. Only when the embodiment is strongly perceived do Proteus-like effects occur and an avatar with dark skin colour increases aggressiveness. de Rooij et al. (2017) further investigate the influence on creativity in an immersive virtual environment with an HMD: An artist-stereotype avatar does not increase creativity, whereas an office-worker-stereotype avatar decreases creativity, which in turn speaks in favour of the Proteus Effect. The researchers attribute this mixed result to the fact that body scans were performed to create the avatars, which could have led to an uncanny valley effect and possibly distorted the results.

A study by Reinhard et al. (2019) measures embodiment by the feeling of body possession and spatial presence within the immersive virtual environment. Here, a comparison is drawn with a control group not wearing HMDs in order to test how long the effect lasts outside the virtual environment. The results indicate that subjects who embody old avatars temporarily walk slower after leaving the virtual environment, which confirms the Proteus Effect. For two thirds of the subjects the effect is intensified by the feeling of spatial presence, whereas the perceived body possession seems to have no influence. Reinhard et al. (2019) conclude that spatial presence is a characteristic of embodiment in immersive virtual environments. Spatial presence appears to be a decisive factor in immersive virtual environments, which may explain the different strength of the Proteus Effect in various virtual environments. In this context, Madary and Metzinger (2016) present the first proposal of an ethical code of conduct for the use of VR and related technology with regard to embodiment in virtual environments. They address the plasticity of the human mind and the lasting psychological effects that embodiment can have, including the Proteus Effect. They further highlight the risks that can arise for individuals and society and give recommendations for ethically correct VR research.

Although many fields are concerned with the influence of the Proteus Effect, there has only been little research, especially concerning reviews of the current state of the art. The existing studies were first summarised in 2019 by Ratan, Beyea, Li & Gracian in a meta-analysis (Ratan et al., 2019). They examined the circumstances under which the Proteus Effect could occur by means of a quantitative study evaluating 46 studies that directly or indirectly examined the influence of avatar characteristics on user behaviour. They also took studies into account that did not explicitly refer to the Proteus Effect but could potentially be attributed to it. Further, it did not distinguish between immersive and non-immersive test environments. The statistical results of the collected studies were used to quantitatively determine how consistent and strong the Proteus Effect has been in the previous studies and which characteristics have contributed most to it. The small-to-medium effect size was consistent, so that Ratan et al. classify the reliability as given. The categories most frequently studied were gender, ethnicity and attractiveness of avatars; yet, there is no reason to assume that the characteristics differ in terms of effectiveness (Ratan et al., 2019). The most frequently measured outcomes are those related to racial prejudice, aggression, and creativity. Influencing factors were also determined, for example, user-avatar closeness, self-similarity, personalisation, and the degree of embodiment with the finding that the Proteus Effect is stronger when the user not only sees but also controls the avatar. According to Ratan et al. (2019), this indicates that the Proteus Effect is enhanced by those factors that create an association between the self and the avatar and lead to self-identification. A difficulty in conducting the meta-analysis arose from the different methods used to measure behaviour, which resulted in a large variance.

While the measurements of attitudes were all based on questionnaires, resulting in a certain homogeneity, this was not the case with the behavioural studies. A further limitation was that studies that had investigated the Proteus Effect in online games were not taken into account because the avatars were not randomly assigned to the players, as in the other studies.

3 Methodology

This theoretical work is based on a thorough literature review of databases such as psycINFO, ScienceDirect, Google Scholar, Microsoft Academic, ResearchGate and internal university databases such as those of the Virtual Human Interaction Lab in Stanford. Keywords are "Proteus Effect"/"avatar" + "self-concept"/"self-perception theory"/"priming"/"deindividuation"/"SIDE model"/"identification"/"virtual environments"/"embodiment", et cetera. By doing a forward search, more studies are identified and then categorised depending on the strength of the reference to the effect.

In contrast to the meta-analysis by Ratan et al. (2019), only those publications that explicitly deal with the Proteus Effect are examined. These can provide information on the researchers' statements and interpretations concerning the theoretical framework of the Proteus Effect. While Ratan et al. (2019) used quantitative methods to determine which factors play a role, this review is intended to qualitatively analyse and compare these influences without the restrictions that were caused by different methods of measurement. In qualitative analyses, it is possible to identify new, previously unknown connections between the existing studies. More open questions and a less predetermined approach can lead to deeper informational content. The sample sizes are usually smaller than in quantitative analyses, but the studies under consideration are more heterogeneous and contain typical representations of the theoretical aspects.

In this paper the studies under consideration had to provide substantive statements and standpoints regarding the Proteus Effect in order to weigh the arguments of the researchers against each other. As the Proteus Effect is not mentioned by name in a certain number of the studies included in Ratan et al. (2019), these studies are not considered. Instead, studies not included by Ratan et al. (2019) because they did not fit the criteria of their meta-analysis (e.g. free choice of avatar), were examined. In order to investigate the extent to which avatar-identification may interact with the Proteus Effect, we incorporated the results of the studies into the model from van Looy et al. (2012). This model was chosen because each identification category indirectly fits the statements from Ratan et al. (2019) without itself referring to the model by van Looy et al. (2012). In a first step, the overlaps with that model are derived from the results of Ratan et al. (2019). Afterwards, the statements of the selected studies are related to the categories of the model by van Looy et al. (2012) (see Fig. 1).

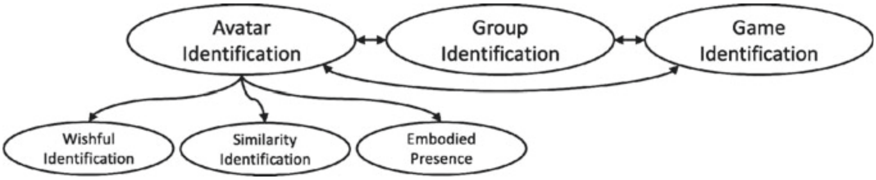

Fig. 1 The model proposed by van Looy et al. with the dimensions avatar, group, and game identification, and the subcomponents wishful identification, similarity identification, and embodied presence, based on van Looy et al. (2012)

4 Literature Review

Explanatory Approaches According to Yee and Bailenson (2007) the conscious search for identity cues is caused by deindividuation, which indicates that the Proteus Effect in its theory is a combination of self-perception theory and the SIDE model. By observing the avatar, one concludes which role is expected. Stereotypes are important cues that help to categorise the self and derive the appropriate behaviour from it. While the SIDE model states that anonymity results from a group situation, Yee and Bailenson (2007) argue that anonymity originates from the embodiment of an avatar that functions as a mask, concealing the actual identity. According to the researchers, this leads to theoretical differences, because where the SIDE model focuses on conformity with the local group norm, the Proteus Effect involves the adoption of identity cues derived from the appearance of the avatar. There is a conceptual difference between having a certain attribute and being part of a group that has a certain attribute. Thus, where the SIDE model is based on the social norms of a group, the Proteus Effect, in contrast, is supposed to occur even when a person is alone. Recently, self-perception theory has been criticised because effects attributed to it could not always be replicated successfully.

The first antithesis to Yee and Bailenson's theory based on self-perception was introduced by Peña, Hancock and Merola in Peña et al. (2009). Groups of subjects whose avatars were dressed in black robes made more aggressive decisions than those who wore white robes. Subjects who had embodied black-clad avatars also experienced a reduced sense of group membership. In the resulting pattern of activation of negative thoughts (aggression), in conjunction with the inhibition of inconsistent thoughts (cohesion/affiliation), the researchers see parallels with the principles of automatic cognitive priming. The thesis presented by Yee and Bailenson (2007) argues that deindividuation leads to the derivation of identity cues from the appearance of the avatar, which leads to a conscious process of self-attribution: The avatar is observed and categorised in order to derive possible actions. Peña et al. (2009) consider this approach unsuitable to explain the effect they observed. According to them, the suppression of inconsistent thoughts indicates that it may rather be a priming process. They assume that the automatic activation of associated concepts unconsciously influences behaviour. It is also possible that deindividuation led to a strengthening of the group norm and hence to an adaptation to the aggressive stereotype of the group. This represents a conceptual difference from the original paradigm of the Proteus Effect proposing that an individual derives his or her self-concept from the avatar and not from the surrounding group. In response to the approach of Peña et al. (2009), Yee and Bailenson (2009) concluded from a study that priming makes little reference to embodiment and therefore a visual stimulus should be sufficient, whereas the self-perception theory assumes embodiment. By comparing the two factors, they were able to show that embodiment was of significant importance for the Proteus Effect, whereas the same purely visual stimulus (without embodiment) had no effect. The meta-analysis by Ratan et al. (2019) refers to the possibility that both priming and self-perception theory in hybrid form could explain the Proteus Effect. They argue that using an avatar causes an association between the user's self-perception and the avatar's characteristics. The more the schema of self-related concepts activated during this process is associated with the schema of avatar-related concepts, the greater the likelihood of conformity to the avatar's characteristics.

Influencing Factors Possible influencing factors are feedback loops such as behavioural confirmation and behavioural compensation. Behavioural confirmation happens if one person's expectations of how another person will behave (e.g., due to the appearance of the avatar as a stereotype) leads to behaviour that causes the other person to confirm the expectation. Yee and Bailenson (2007) hypothesised that the Proteus Effect could lead to a reversal of behavioural confirmation: A subject's false self-concept would then cause them to interact with another person in such a way that the other behaves in a way that confirms the subject's false self-concept. This has not yet been investigated and thus constitutes a research gap. Another feedback loop is behavioural compensation which occurs if the expectation of a person that they will be judged negatively (e.g. due to the appearance of their avatar as a stereotype) causes them to behave towards another person in a way that counteracts or compensates for this, as a study by van der Heide et al. (2012) shows. Both effects conflict with the paradigm of the Proteus Effect, since it is based on an intrapersonal process that occurs independently of the presence of others. Feedback loops, on the other hand, occur through interpersonal dynamics and are therefore disparate.

In contrast, stereotype threat and stereotype lift effects can lead to a self-fulfilling prophecy when the Proteus Effect occurs. In the one case the fear of conforming to a negative stereotype leads to a confirmation of the stereotype; in the other, the awareness of not belonging to a negatively stereotyped social group leads to a positive effect on one's own performance, as a study by Lee et al. (2014) shows. Stereotype threat and stereotype lift are both compatible with the paradigm of the Proteus Effect as they show that the stereotype of the avatar has been integrated into the self-concept; as such, they can both be used to explore the Proteus Effect.

An older, but broader discussion of our literature review's results can be found in Praetorius and Görlich (2020b).

5 Theoretical Framework

Our first and therefore less comprehensive analysis of the Proteus Effect's theoretical framework was already published in Praetorius and Görlich (2020a). Figure 2 summa-rises the current state of our analysis as of August 2020: The theoretical framework of the Proteus Effect is based on self-perception theory and assumes that thinking and behaviour is influenced by a conscious observation of the avatar (Yee and Bailenson 2007). During deindividuation, identity cues of the avatar are internalised and (temporarily) integrated into the self-concept. Priming, as an alternative explanatory approach, assumes that this process is an unconscious and automatic behavioural assimilation, which can be explained by the activation of associations and the suppression of inconsistent concepts (Peña et al. 2009). Another approach assumes a hybrid of both concepts, based an association between the user's self-perception and the avatar's characteristics (e.g. identification, embodiment, etc.) (Ratan et al. 2019).

Identification Unlike traditional media, digital games and virtual worlds give the user an active role, which, according to van Looy et al. (2012), can be seen in the fact that players refer to their identity in the game as "I" and the virtual environment as "here". However, this does not always necessarily occur: Banks (2015), among others, researches player-avatar relationships (PAR). She proposes a spectrum ranging from highly social PARs with high self-differentiation, intimacy, and avatar agency down to highly unsocial PARs with low self-differentiation, low intimacy, and high player agency. She suggests a social typology with four types of PAR: Avatar-as-Object, Avatar-as-Me, Avatar-as-Symbiote, and Avatar-as-Social-Other. Though it is likely that different levels of identification and strengths of the Proteus Effect might occur depending on the type of player-avatar relationship established, this assumption constitutes another research gap. Identification with the game character

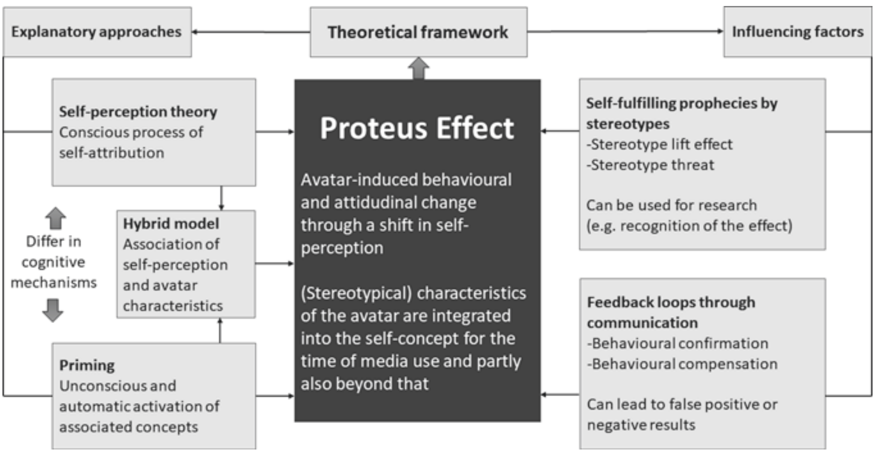

Fig. 2 Theoretical framework of explanatory approaches to and potential influences on the proteus effect

can be seen as a temporary shift in self-perception, in which the player undertakes a kind of self-priming. This makes it possible to incorporate characteristics of the avatar's character into the player's self-perception for the time of representation in the virtual environment. In this way, the avatar can be classified as a self-concept alongside other self-concepts such as the authentic and ideal self. Van Looy et al. (2012) describe avatar-identification as one of three dimensions of identification in a three-dimensional model, and attribute self-similarity, wishful identification, and embodied presence as subcomponents to the avatar-identification dimension (see Fig. 1). There are also other factors such as game identification, or group identification, but those are related to the social dimensions and not to the player-avatar bond.

Similarity Identification According to van Looy et al. (2012), identification via self-similarity is based on the assumption that similarity with one's self leads to higher self-relevance of the avatar, because more personally relevant information can be derived and therefore there is a tendency to adopt the expected behaviour of the avatar. Similarity is considered an integral component of the identification model as it facilitates mental rapprochement between player and character.

The correlation between self-similarity and the Proteus Effect has already been demonstrated in various studies. The meta-analysis by Ratan et al. (2019) states that the Proteus Effect is increased when users associate self-related and avatar-related schema. For example, a study by Fox et al. (2012) shows that an avatar physically resembling the test subject leads to a much stronger Proteus Effect than a generic avatar. However, a study by de Rooij et al. (2017) leads to mixed results. De Rooij et al. attribute this to either an unsuitable choice of stereotype, or technological difficulties, because of the body scan procedure, which might have caused an uncanny valley effect and thereby possibly counteracted identification through self-similarity.

This shows that self-similarity does not necessarily trigger the Proteus Effect, but without counteracting influences, it can increase the effect. The choice of stereotype also plays a role regarding its association with the desired concept.

Wishful Identification In contrast, wishful identification, the second dimension, shows that dissimilarity can also appear desirable. According to van Looy et al. (2012) this is the case if the avatar represents a desirable trait, such as attractiveness, which a person assumes he or she does not possess—at least, not to the same or to the desired extent. For the time of avatar use, this results in identification that in turn leads to the elimination of discrepancy between the self-image of the person and the desirable qualities of the avatar.

Attractiveness is one of the most frequently manipulated factors in studies concerning the Proteus Effect, as the meta-analysis by Ratan et al. (2019) reveals. Attractiveness is referred to as a generally positively connoted characteristic, which is associated with traits such as friendliness and openness (Yee & Bailenson, 2007; Yee & Bailenson, 2009; Yee et al., 2009; van der Heide et al., 2012; Bian et al., 2015). Attractiveness can thus be interpreted as a potentially desirable characteristic, although this is always determined by the respective context, as a study by Yee et al. (2009) shows, because which characteristic appears desirable also depends on the situational circumstances and the respective stereotype interpretation. Bian et al. (2015) show that the influence of a desirable trait such as attractiveness can be so strong that even individual personality traits such as shyness are hidden temporarily. In contrast, van der Heide et al. (2012) find that an unattractive appearance can be perceived so negatively that behavioural compensation occurs instead of a Proteus Effect. Also, McCain et al. (2018) cannot detect a Proteus Effect when they examine whether an undesirable characteristic of the avatar would be adopted after embodiment or not. They conclude that avatar users consider in much more depth than the Proteus Effect would predict which traits are desirable for them and dissociate themselves from negative feedback. This could be a boundary condition for the Proteus Effect, as individuals strive to improve their self-perception and not undermine it (McCain et al., 2018).

These findings indicate that wishful identification can promote the Proteus Effect, but undesirable characteristics can be a barrier as they may provoke a countermovement or compensation. In both cases, however, the situational context within a virtual environment determines which traits seem more or less desirable.

Embodied Presence The International Society of Presence Research defines presence as a psychological state in which the role of technology is not consciously perceived (Riva, 2009). The recipient is not aware of the virtuality of the experience and a sense of embodiment in the virtual environment is created. van Looy et al. (2012) therefore refer to this as "embodied presence" which is not limited to immersive virtual environments and can thus be transferred to other versions of a virtualised self.

Ratan et al. (2012) identify embodiment as an important factor in the study of the Proteus Effect. This is confirmed by the results of a study by Yee and Bailenson (2009) which shows that embodiment in an immersive virtual environment has a different effect than just looking at the same visual stimulus. They conclude that there is a fundamental difference between being and seeing, which they attribute to self-perception and priming. The way in which embodiment is measured can also vary. For example, a study by Reinhard et al. (2019) measures the perceived embodiment by spatial presence and the feeling of body possession during a user's time in the immersive virtual environment. According to Reinhard et al. (2019), the perceived body possession has no influence on the subsequent occurrence of the Proteus Effect. The Proteus Effect occurs independently of this factor, but for two thirds of the participants a feeling of spatial presence in the virtual environment proves to be a strong predictor for the Proteus Effect. Reinhard et al. (2019) conclude that spatial presence is a characteristic of embodiment in immersive virtual environments.

This indicates, but does not prove, that embodiment can have stronger effects than other forms of self-representation, and although embodiment does not necessarily trigger the Proteus Effect, it does play an important role for the user-avatar bond and can therefore represent a threshold for self-perception from the avatar's perspective.

User-avatar connection expresses itself on these different levels and is thus conducive to the occurrence of the Proteus Effect. Accordingly, the Proteus Effect could also be understood as an identification process that takes place intrapersonally in the interaction between user and avatar. It must always be assumed that social dynamics also have an influence and that interpersonal factors such as feedback loops and group identification may also have a stronger effect than the Proteus Effect. Future empirical research must show whether the Proteus Effect is able to override those influences and thus might lead to a reverse behavioural confirmation.

6 Conclusion and Outlook

The theoretical framework of the Proteus Effect is still largely unexplained, as the effect was discovered and named only a decade ago. We have therefore analysed dozens of publications, studies and experiments focusing on or referring to the effect. By reviewing them and classifying them according to their findings and conclusions about the theoretical framework of the Proteus Effect and its explanatory approaches we showed that a one-sided ascription to self-perception theory or priming may not be sufficient and that there are potential moderators of the effect such as embodiment, identification and interpersonal interaction.

However, the broad spectrum of the studies examined here has shown that many fields of research can benefit from an examination of the Proteus Effect. It is of relevance to questions of cognitive science insofar as it deals with conscious and unconscious thought processes, such as self-perception theory and priming. Another area is media psychology since computer-mediated communication plays a key role in research into the Proteus Effect. It has been shown that interpersonal interaction involves a variety of different influencing factors. The question of the extent to which behaviour is shaped by the possibility of alternative identities and how social identity and stereotypes affect the self in case of deindividuation will become increasingly important in the current age of digitalisation. Practical fields of application can also benefit from the findings, since avatars are omnipresent, starting with social media, virtual worlds, and even complete immersion in virtual realities. They form a projection surface and at the same time they offer a possibility for self-transformation. Positive effects can be achieved, such as increasing creativity or reducing fears, but also negative ones, such as self-objectification and hostility. Research into the Proteus Effect can provide clues as to which criteria play a role in this and how identification with the avatar can be used effectively to achieve the desired effects in a targeted manner.

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Immersive Technology Adoption

Modifying the Technology Acceptance Model to Investigate Behavioural Intention to Use Augmented Reality

Aleksandra Zheleva, Anne Roos Smink, Paul Hendriks Vettehen, and Paul Ketelaar

Abstract Online retailers are employing interactive technologies to reduce the risk of online purchases. Augmented reality (AR) serves this aim by placing virtual 3D objects (e.g., new furniture) into the consumers' homes. This study investigates the consumer's acceptance of AR applications via a modified Technology Acceptance Model (TAM). Also, we examined the effect of products associated with either high or low financial risk on the relationship between perceived usefulness and behavioural intention. We conducted a single case study with a field between-subject design. The results confirmed the relationships in the modified TAM. In particular, enjoyment had both a direct and indirect positive effect on the behaviour intention of consumers to use the AR app in the future. However, product type did not have a significant effect.

Keywords Augmented reality (AR) · Technology acceptance model (TAM) · Product type

1 Introduction

Augmented reality applications (AR apps) can enhance the consumer experience by merging highly customizable digital content with the touch-and-feel quality of the physical environment. For instance, consumers can place a virtual 3D sofa in their living room and try in real-time if the sofa fits in their room, which can reduce the risk of online purchase and deliver better shopping value for consumers (Dacko, 2017). Retailers have been quick to catch on the added value of AR, which has led

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to an overall increase in investment and implementation of AR in online shopping (PerkinsCoie, 2018). While the innovative nature of AR can help an online retailer to stand out, if the AR technology is not developed in a way that is useful for the consumers, then they might not use it again. The current study helps AR developers in this area by gaining information about the mechanisms that underlie the consumer's intention to adopt AR.

AR studies have employed the Technology Acceptance Model (TAM; cf. Davis, 1989) to understand what drives consumers' intention to use the technology. Four main factors have been established to affect the consumer's behavioural intention to use AR—perceived usefulness, perceived ease of use, perceived enjoyment, and perceived informativeness (Kim & Forsythe, 2008; Rese et al., 2017). The current study extends previous findings in the following ways.

First, previous research has been conducted in laboratory settings. Thus, the consumers' feedback has been restricted to their experience in a not-so-realistic setting (i.e., a lab room). To this point, the current study adopts a more ecologically valid approach by conducting the experimental sessions in participants' homes.

Second, perceived enjoyment has been considered separately as a factor impacting directly perceived usefulness (Rese et al., 2017) and also a factor that has a direct effect on behavioural intention (Kim & Forsythe, 2008). It is unknown, however, whether both ideas about the role of perceived enjoyment may be accurate at the same time. This knowledge can provide insight into the applicability of the (modified) TAM in the context of AR. Moreover, knowledge about the role of perceived enjoyment may be useful in developing future AR apps in this area.

Finally, while previous studies have focused on the experience of the consumer and its effect on their intention to use AR (Dey et al., 2018), this study also investigates the effect of external factors (i.e., product type). In particular, in evaluating products using an AR app, the stakes are higher for high-risk products than for low-risk products. This might imply that app's perceived usefulness has a direct effect on the user's behavioural intention to use the app in the future. All proposed relationships are visualised in Fig. 1.

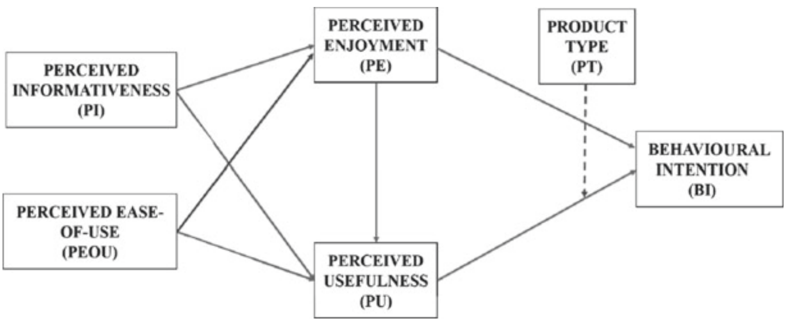

Fig. 1 The modified TAM model illustrating the hypothesized relationships between product type, perceived informativeness, perceived enjoyment, perceived usefulness, perceived ease of use and behavioural intention

2 Theory and Hypotheses

A meta-analysis of studies using the TAM model concludes that TAM is a valid and robust predictive model (Legris et al., 2003). Furthermore, because of its simplicity and parsimony, the model was chosen as the base theoretical model for the current study. TAM is built on Fishbein and Ajzen's theory of reasoned action (TRA), which explains how the individuals' intentions to behave in a certain way are correlated with their attitudes towards the behaviour and beliefs in the form of subjective norm (Ajzen, 1991). Thus, the model's purpose is to predict what features (i.e., variables) influence consumers' intentions to use innovative technology in the future.

The original TAM illustrates that consumers' behavioural intention to use technology is influenced by its *perceived usefulness* (i.e., "the degree to which a person believes that using a particular system would enhance his or her job performance") (Davis, 1989, p. 320). Rese et al. (2017) provided support for this relationship in the context of AR apps. However, their study was conducted in a strictly controlled lab environment. Acknowledging that these kinds of AR apps are purposefully designed to be used by customers in their homes, we tested this effect in a field experiment.

H1. Perceived usefulness has a direct positive effect on behavioural intention.

Furthermore, studies have illustrated that the perceived usefulness of the technology can be influenced by both hedonic (i.e., aim to provide a fun experience for the user) and utilitarian (i.e., aim to support users in fulfilling their goals) factors (Rese et al., 2017). Therefore, the current research will modify the original TAM model by including two variables: *perceived enjoyment* (hedonic) and *perceived informativeness* (utilitarian). Perceived enjoyment is to what degree the consumer believes the technology is playful, entertaining, and satisfies the need "for escapism, diversion, aesthetic enjoyment, or emotional release" (Ducoffe, 1996, p. 23). In a series of lab experiments, Rese et al. (2017) showed that perceived enjoyment was a strong determinant of the perceived usefulness of AR applications. Thus, we expect to find the same relationship in the current field study.

H2. Perceived enjoyment has a direct positive effect on perceived usefulness.

Additionally, Olsson et al. (2012) and Rese et al. (2017) have shown that higher *perceived informativeness* results in higher perceived usefulness of AR apps. Perceived informativeness is to what degree the consumer believes that the technology provides them with relevant and useful information about the product. The effect of perceived informativeness on the perceived usefulness of AR shopping apps, could be due to the nature of those apps. More specifically, AR shopping apps aim to provide customers with relevant information about the product that they consider buying. We suggest that if the app is perceived as giving appropriate and applicable information about the products, the consumers will not merely perceive the app as more useful, but will also enjoy using the app more.

H3. Perceived informativeness has a direct positive effect on (a) perceived usefulness and (b) perceived enjoyment.

Furthermore, Davis suggested that "ease of use operates through usefulness" (Davis, 1989, p. 332). *Perceived ease of use* is "the degree to which a person believes that using a particular system would be free from effort" (Davis, 1989, p. 320). Indeed, Rese et al. (2017) and Brito et al. (2018) have shown that higher perceived ease of use of AR apps is predictive of higher perceived usefulness. Furthermore, research has established a correlation between perceived ease of use and perceived enjoyment (Kim & Forsythe, 2008; Rese et al., 2017). The rationale is that systems that are perceived as easier to use are more likely to be perceived as enjoyable (Teo & Chia, 2018).

H4. Perceived ease of use has a direct positive effect on (a) perceived usefulness and (b) perceived enjoyment.

Not only does AR give additional information about products, but at the same time, it offers hedonic value (Olsson et al., 2012, p. 296). Research on trends of traditional online shopping has revealed that perceived enjoyment has a strong positive effect on behavioural intention to use the online platform in the future (Cheema et al., 2013). Furthermore, it could be that perceived enjoyment also has a direct positive effect on the behaviour intention of consumers to use AR apps.

H5. Perceived enjoyment has a direct positive effect on behavioural intention.

Previous AR studies based on TAM have mostly focused on the experience of consumers and its effect on their intention to use AR (Dey et al., 2018). However, external factors, such as what products the technology is used for, have not been investigated. It is essential to consider this factor because different products might carry a different amount of risk when purchased online. According to Pristiwa et al. (2017), perceived risk can influence consumer's behaviour regarding the online platform they are shopping from. A major type of risk that impacts the consumer's behaviour is the financial risk (Thakur & Srivastava, 2015).

AR can be viewed as a tool that decreases the consumer's perceived financial risk during online shopping because it offers additional visual information about the product (Rese et al., 2017). Research has shown that financial risk is related to the risk of losing money through a purchase decision (Derbaix, 1983; Horton, 1976; Sweeney et al., 1999). Indeed, financial risk is correlated with price. For instance, if the price of a given product is higher, then the perceived financial risk is also higher. Financial risk has been pointed out by previous research as one of the most significant features of the overall perceived risk in shopping (see e.g., Kaplan et al., 1974; Stone & Grønhaug, 1993). To counterbalance this risk, an increasing number of retailers are integrating AR into their online shops as it can function as risk insurance. Indeed, it is for this reason that it is of the utmost importance that the app does a good job in terms of usefulness. This is expected to be particularly the case with high-risk products because the potential losses then are higher in case the app would prove useless.

H6. The positive relationship between perceived usefulness and behavioural intention is stronger for high-risk products than for low-risk products.

3 Methodology

3.1 Study Design

The design of a field experiment was chosen because the environmental factors of a home (e.g., space configuration) needed to be present naturally. This improved the ecological validity of the results because the AR app used as a stimulus is developed for consumers to use at their houses. Participants were divided into two groups: low-risk group (n = 48)—participants had to place low-risk products that cost between €10–€30 in their room, and high-risk group (n = 44)—participants had to place high-risk products (€100–€300) in their room.

3.2 Participants

Data were gathered from 100 students. Eight of the participants were excluded from the analyses as they did not use the correct stimuli. Thus, the analysis is based on data from 92 participants ($n_{female} = 69$, $M_{age} = 23$, $SD_{age} = 4.40$). Additionally, none of the participants have used the IKEA Place app before. Participants were divided into two groups: (1) low-risk group (n = 48)—participants had to place low-risk products in their room and (2) high-risk group (n = 44)—participants had to place high-risk products in their room.

3.3 Stimulus Material

All participants used the AR smartphone app IKEA Place. The app was chosen because it has a simple design and does not send distracting messages (Rese et al., 2017). Participants could browse through the IKEA catalogue and tap on an item. Then, the floor and walls of the room were scanned by the camera phone, and a virtual object was placed in the physical space. Then, the item could be moved to the preferred location and/or rotated (Fig. 2).

A *Favourites* list was created in the app (Fig. 3). The list included eight furniture products. Four of the products were low-risk (Fig. 3a), and the other four were high-risk (Fig. 3b). The product s were chosen so that they correspond to each other. For instance, a cheap wardrobe in the low-risk group corresponded to an expensive wardrobe in the high-risk group.

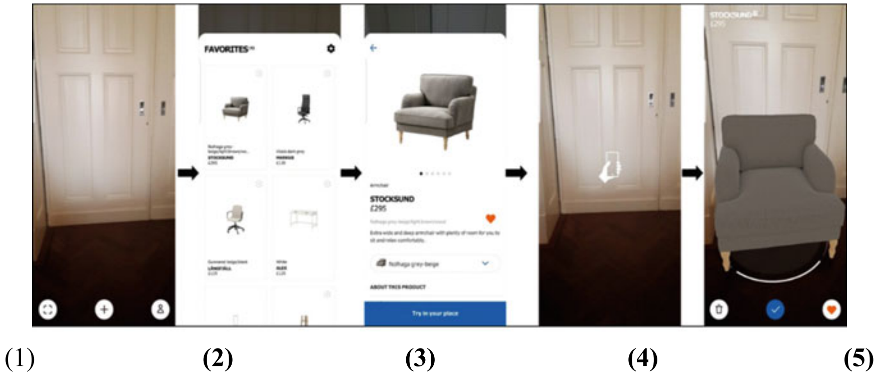

Fig. 2 Sample visualization of the use of the IKEA Place app. From right to left: **a** The app is opened, and the phone camera is pointed towards the desired location in the room; **b** Participants choose an item; **c** Participants view details (i.e., price) of the object and tap on the "Try in your place tab"; **d** The app scans the room; **e** The object is placed in the scanned place

Fig. 3 **a** The four low-risk visual stimuli used in the research; **b** The four high-risk visual stimuli used in the research

3.4 Procedure

The procedure started with a visit from the experimenter in the participant's home. Prior to this, participants were asked to clear a wall in their homes (i.e., move around their furniture), to use the app without any obstacles. The visit started with a short information and consent form procedure. Then, participants were given a list of instructions and used the IKEA Place App to place four furniture objects in a room in their home. To not interfere with the participants' experience, the researcher was not present in the room. After finishing the task, participants were asked to fill in an online questionnaire (10 min). Finally, participants were debriefed and reimbursed.

3.5 Variables and Measurement Instrument

We measured variables with an online questionnaire. The full version of the questionnaire can be found in Appendix 1 at https://bit.ly/3eYwXId. First, we asked participants for their age, gender identification, and previous use of the IKEA Place app. Then, we measured the four independent variables, one dependent variable, and four control variables. The questionnaire was based on validated and reliable tools explained below.

Perceived informativeness (PI). The first independent variable was measured with four questions used in the Rese et al. (2017) study. The questions included statements such as: "The IKEA app provides detailed information about the furniture."; "The IKEA app provides the complete information about the furniture.". Participants had to show their level of agreement with each of the statements on a 7-point Likert scale, anchored from 1 (strongly disagree) to 7 (strongly agree). The PI scale ($M = 5.21$; $SD = 1.02$) was reliable ($\alpha = .866$).

Perceived enjoyment (PE). The second independent variable was measured with four questions used in the Rese et al. (2017) study (Cronbach's $\alpha = .892$). The questions included statements such as: "Using the IKEA app is really fun."; "The scan function and its elements are a nice feature.". Participants had to show their level of agreement with each of the statements on the previously mentioned 7-point Likert scale. The PE scale ($M = 5.38$; $SD = .96$) was reliable ($\alpha = .89$).

Perceived ease of use (PEOU). The third independent variable was measured with four questions used in the Rese et al. (2017) study. The questions included statements such as: "I found the IKEA app to be very easy to use."; "The IKEA app was intuitive to use." Participants had to show their level of agreement with each of the statements on the same 7- point Likert scale. The PEOU scale ($M = 5.01$; $SD = 1.25$) was reliable ($\alpha = .89$). *Perceived usefulness (PU).* The fourth independent variable was measured with four questions used in the Rese et al. (2017) study. The questions included statements such as: "For me, the IKEA app has great value."; "The IKEA app provides beautiful interior design ideas.". Participants had to show their level of agreement with each of the statements on the same 7-point Likert scale. The PEOU scale ($M = 4.81$; $SD = 1.25$) was reliable ($\alpha = .91$).

Behavioural intention (BI). The dependent variable was measured with five questions used in the Rese et al. (2017) study. The questions included statements such as: "If I were to buy furniture in the future, I would: …download or use the IKEA app immediately; …give the IKEA app priority over the printed catalogue.". Participants had to show their level of agreement with each of the statements on the same 7-point Likert scale. The BI scale ($M = 4.41$; $SD = 1.28$) was reliable ($\alpha = .91$).

Affinity with interior design (AID). This control variable is defined as a participants' enduring involvement with interior design. We expect that since the IKEA Place app involves making an interior design decision about one's own home, participants who have a higher interest in the topic might perceive the app as more enjoyable and informative. The variable was measured with The Enduring Involvement Scale (Bruner, 2015). Participants had to use a 7-point scale to give a numerical expression of their opinion on statements such as: "I find Interior Design is: "1 = unimportant/7 = important"; "1 = uninteresting/7 = interesting". The AID scale ($M = 5.40$; $SD = .98$) was reliable ($\alpha = .94$).

Attitude towards the company (ATC). Since the AR application that participants used during the study was related to the IKEA brand, we suspected that if a participant has an extreme attitude towards IKEA, this will influence how enjoyable and useful they will find the app. Therefore, we measured participants' attitudes towards the company using the Attitude Toward the Company Scale (Bruner, 2015).Participants had to use a 7-point scale to express their opinion towards IKEA on items such as: "1 = Negative/7 = Positive"; "1 = Unfavourable/7 = Favourable". The ATC scale ($M = 5.29$; $SD = 1.06$) was reliable ($\alpha = .84$).

Technological innovativeness (TI). We expected that people who are more technologically innovative would find the app more informative and useful because they are more inclined to use new technology as a reliable source of information. Therefore, we used the Technological Involvement Scale as included in the Bruner scales manual (2015). The questions included statements such as: "Other people come to me for advice on new technologies."; "In general, I am among the first in my circle of friends to acquire new technology when it appears.". Participants had to show their level of agreement with each of the statements on a 7-point Likert scale anchored from 1 (strongly disagree) to 7 (strongly agree). The TI scale ($M = 4.21$; $SD = 1.04$) was reliable ($\alpha = .91$).

Finally, the last question checked whether the experimental task was completed correctly. We asked participants to choose pictures of the objects that they used the app for. As previously mentioned, participants who failed to use the correct stimuli ($N = 8$) were excluded from the data analysis.

4 Results

First, we examined the presence of outliers, prevalence, and patterns of missing values, and normal distribution of the data. We concluded that the data included five outlier values ($>M + 3SD$)—one in perceived enjoyment, two in perceived usefulness, one in perceived ease of use, and one in attitude towards the company. To decide whether to exclude the outliers from the main analysis we followed Sweet and Grace-Martin (2012) guidelines which state that outliers are deleted only if: (1) they are a wrong entry or (2) they are some special cases isolated from a common phenomenon the analysis. Both guidelines that are listed above do not apply to the current data set and analysis. First, because the outliers are still entered on the same pre-defined scale with a limited fixed range. Second, because not all outliers came from the same participants in the same product group. Thus, we cannot say with confidence that some common unforeseen circumstances have resulted in these outliers and therefore they do represent the tested sample. Moreover, additional analyses showed that exclusion of the outliers did not alter the study findings substantially. Below, we report the data analysis and results of the data set with outliers.

Second, we checked if the control variables are correlated with any of the main variables. Age was not significantly correlated with any of the main variables. Affinity towards interior design had a significant positive association with perceived usefulness (r (92) = .20, $p < .05$) and behavioural intention (r (92) = .21, $p < .05$). Attitude towards the company had a significant positive association with perceived informativeness (r (92) = .29, $p < .01$), perceived usefulness (r (92) = .21, $p < .05$), perceived enjoyment (r (92) = .29, $p < .05$), perceived ease of use (r (92) = .21, $p < .05$) and behavioural intention (r (92) = .22, $p < .05$). Finally, technological innovativeness had a significant positive association with perceived usefulness (r (92) = .22, $p < .05$).

Finally, we used linear regressions controlling for age, affinity towards interior design, attitude towards the company and technological innovativeness. The results of the hypotheses testing are summarized in Fig. 4. The analysis showed that the effect of perceived usefulness on behavioural intention was significant ($\beta = .35$, $SE = .09$, $p < .001$), as well as the effect of perceived enjoyment on perceived usefulness ($\beta = .24$, $SE = .11$, $p < .05$). Next, the effect of perceived ease of use on perceived enjoyment was not significant ($\beta = .15$, $SE = .09$, $p = .13$). Perceived ease of use had significant positive effect on perceived usefulness ($\beta = .23$, $SE = 2.39$, $p < .05$). Also, the effect of perceived informativeness on perceived usefulness was significant ($\beta = .23$, $SE = 2.18$, $p < .05$) as well as the effect of perceived informativeness on perceived enjoyment ($\beta = .33$, $SE = .10$, $p < .01$). Lastly, perceived enjoyment had a direct positive effect on behavioural intention ($\beta = .44$, $SE = .09$, $p < .001$) but product type was not a significant moderator of the relationship between perceived usefulness and behavioural intention ($\beta = .05$, $SE = .03$, $p = .49$).

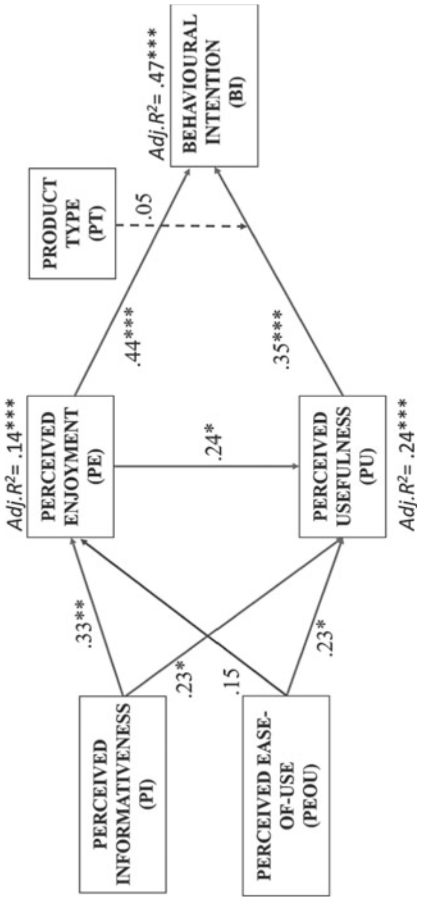

Fig. 4 The modified TAM model illustrating the results of the hypothesized relationships between product type, perceived enjoyment, perceived informativeness, perceived usefulness, perceived ease of use and behavioural intention (N = 92)

5 Discussion

The main findings of the study are: (1) the results from earlier studies using the (modified) TAM model can be replicated in a study with a field design; (2) perceived enjoyment is a factor that has both a (strong) direct influence and a weaker indirect influence on behavioural intention (3) product type does not moderate the impact of perceived usefulness on the intention to adopt AR apps.

Regarding the modeled TAM relationships, Rese et al. (2017) have shown that perceived usefulness has a direct effect on behavioural intention. Also, Kim and Forsythe (2008) have considered its direct influence on behavioural intention. The current study, however, shows that both of these effects exist simultaneously. However, perceived enjoyment had a stronger direct effect on behavioural intention than perceived usefulness. Furthermore, perceived enjoyment also directly influenced perceived usefulness. These two findings illustrate that perceived enjoyment could be a more important aspect of retail AR apps than previously thought. Thus, future studies can invest in efforts to replicate these results to establish a clearer idea of the role of perceived enjoyment in the experience of AR technology in retail.

Contrary to our expectations, we did not find an effect of product type on the relationship between perceived usefulness and behavioural intention. The insignificant difference between product groups could be attributed to our study sample, which consisted of students. The general lack of financial opportunity to buy the relatively expensive products might have resulted in participants in the high-risk group not experiencing a financial risk of the product (Bagga & Bhatt, 2013; O'Liery, 2017). As a result, the low-risk versus high-risk factor did not have the expected effect. Future studies in different samples could shed light on the value of this explanation.

Most importantly, the current study tested the TAM model in field settings that were not controlled by the researcher. This is in contrast with most previous research on TAM, which has been conducted in controlled and artificial settings (i.e., a research lab) (Brito et al., 2018; Rese et al., 2017). By making use of a more realistic setting (i.e., the participants' home), the current study added to the ecological validity of previous research findings. Thus, by taking all the previous experimental evidence together with the current results, this study's outcomes suggest that the TAM model is a valid and generalizable theoretical model for studying the acceptance of AR in 'real-life' settings.

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Immersive Technology in Education

Using Virtual Reality as a Form of Simulation in the Context of Legal Education

Justin Cho, Timothy Jung, Kryss Macleod, and Alasdair Swenson

Abstract Simulation is a form of learning that is often used in legal education to teach practical skills that cannot be effectively taught in the traditional classroom environment. Despite its frequent use, its capabilities as a learning tool is limited. Efforts have been made to enhance simulated learning with novel digital technologies. Virtual Reality is an example of a novel technology that has seen an increase in use in the context of education. This paper introduces the literature on legal simulation and VR education and provides theoretical grounding for the potential effect that VR may have in legal simulation.

Keywords Legal education · Simulation · Virtual reality · Immersive technology · Learning theory

1 Introduction

The traditional casebook and lecture method of teaching in legal education has long been criticised as insufficient in teaching practical legal and professional skills (Daly & Higgins, 2011). As a result, legal education often employs simulations to address this problem (Daly & Higgins, 2011).

Simulations encourage deep learning by providing a safe and innovative environment in which students are able to actively engage with the practical applications of the law, helping students to find motivation, develop confidence, contextualise legal doctrine and identify gaps within their existing knowledge that cannot necessarily be found through conventional classroom methods (Waters, 2016; Maharg & Nicol, 2014; Daly & Higgins, 2011). However, the effectiveness of simulated learning is limited. A lack of reality/authenticity of the simulation is often found to be the cause of a lack of immersion of the students, which leads to ineffective learning (Waters, 2016).

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The recent proliferation of digital technologies and their enhanced functionalities have contributed to the development of simulations (Maharg & Nicol, 2014). It has been found that the use of technology in simulation allows for innovative content delivery, creating a rich and situated problem space that engages and immerses the participant (Newbery-Jones, 2015). Virtual Reality is a technology that has recently seen an increase in use in the context of education (Kavanagh et al., 2017) due to its decreasing cost and the increasing availability of high speed internet (Merchant et al., 2014; Van Ginkel et al., 2019). Studies conducted on educational VR have shown that the novelty and the realistic quality of the technology increases engagement and motivation, and as a result, the immersion of the students (Kavanagh et al., 2017).

The purpose of this literature review is to provide an introduction to the literature related to the potential role of Virtual Reality as a form of simulation in legal education. In order to achieve this aim, this paper will present a critical analysis of three main areas of knowledge: Simulation in legal education, Virtual Reality in education and Learning theory.

2 Methodology

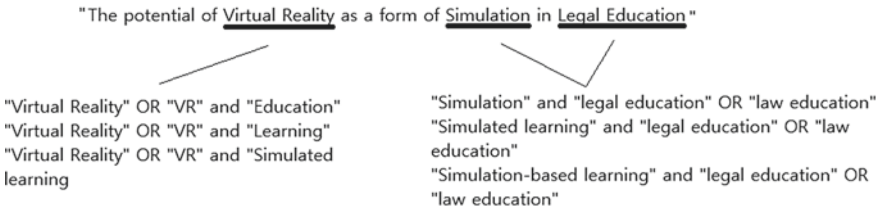
Although the use of Virtual Reality technology [VR] has been introduced in areas of education such as health, engineering, and construction (Kavanagh et al., 2017), use of VR, and virtual environments generally, in legal education are very scarce (Thanaraj, 2016). As a result, an exploratory approach was taken in this review with the aim of identifying factors that may contribute to the effectiveness of the future use of VR in legal education from the three areas stated above. Therefore, the literature was approached with the following review questions: (1) How has simulation impacted learning in legal education, and how has the use of technology changed simulated learning in this context? (2) What has been the impact of Virtual Reality technology in education? (3) What pedagogical motivations and theories underly (A) Simulation in legal education; and (B) Virtual Reality in general education?

In order to produce a credible and accurate review of the literature, sources were limited to peer-reviewed journal articles and books. In the legal simulation article search, common law jurisdictions including the UK, US, and Australia were reviewed and simulation was broadly defined as "any heuristic that involves simulation of any aspect of legal theory or practice within a legal education context and for an educational purpose" (Maharg & Nicol, 2014: 3). Furthermore, the term 'practical skills' was taken to represent general soft skills that are applicable in any job, subject specific skills and ethical awareness/professionalism (Newbery-Jones, 2015: 9).

Parong and Mayer (2018) makes clear the need to distinguish between immersive Virtual Reality and non-immersive Virtual Reality when defining VR. Immersive VR usually involves the use of a Head Mounted Display (HMD) to fully immerse the user in an artificial environment in which the user can move and interact (Parong & Mayer, 2018). Non-immersive VR is a virtual environment in which the user can make various interactions usually through a computer screen (Parong & Mayer, 2018).

This review used a broad definition of Virtual Reality to encompass both immersive and non-immersive VR. It employed Encyclopaedia Britannica's (2015) definition of "The use of computer modelling and simulation that enables a person to interact with an artificial, three-dimensional visual or other sensory environment" (Sala, 2016: 2).

The following key terms represented in the figure below were used to search the literature.



Common themes found in the articles chosen were analysed and are presented as a literature synthesis in the section below.

3 Literature Review Results

3.1 Simulation in Legal Education

The various forms of simulation

The literature revealed a number of applications of simulation currently being used, all with similar but slightly varying pedagogical motivations and therefore outcomes.

The most commonly used form of simulation seems to be mooting—a mock trial of a hypothetical or real case in which students act as lawyers arguing their cases before a judge and jury (Parsons, 2017; Daly & Higgins, 2011; Knerr et al., 2001).

Simulated learning is also used generally in the form of case studies. Simulation case studies place students in the role of the practitioner and create stories in which students can immerse themselves into (Boyne, 2012).

Negotiation and mediation exercises are forms of simulation that are focused on the learning of a much more specific set of skills. Simulated negotiations and mediation exercises use hypothetical or real disputes to provide a more holistic understanding of the realities of the negotiation and dispute resolution processes to students (Waters, 2016; Byrnes & Lawrence, 2016).

More recently, with the enhanced functionalities of modern technology, simulated virtual learning environments (VLE) have been introduced (Thanaraj, 2016). Virtual learning environments have similar motivations and aims to simulated case studies in the sense that a big portion of the learning is done by playing a role in the specific scenario (Thanaraj, 2016; Newbery-Jones, 2015).

Emergent themes in simulation

LEGAL SKILLS: The most obvious and apparent theme is the improvement of legal skills. In a simulation conducted by Byrnes and Lawrence (2016), it was found that the students believed themselves to have gained a much better grasp of negotiation specific skills. In the context of mooting, it was found that students generally saw an improvement in their advocacy, case analysis and legal reasoning skills (Daly & Higgins, 2011; Knerr et al., 2001). The use of simulation in general has been found to be effective in helping students to apply legal knowledge into realistic contexts (Philips, 2012; Widdison et al., 1997; Parsons, 2017; Waters, 2016; Newbery-Jones, 2015).

LEGAL KNOWLEDGE: Studies also found that simulation was also effective in the learning of substantive knowledge and in gaining a deeper understanding of the law (Apel, 2017; Daly & Higgins, 2011; Knerr et al., 2001). Furthermore, simulations are useful in identifying gaps in the existing knowledge of students (Philips, 2012; Thanaraj, 2016). However, although Byrnes and Lawrence (2016) agree that simulations are effective in increasing engagement and retention, they question as to whether simulations are always effective in the learning of facts.

TRANSFERABLE SKILLS: The development of more general skills was also identified. Parsons (2017) describes how mooting helped students to gain confidence and resilience. Philips (2012) also commented how the often-cooperative nature of simulation also allows for the training of soft skills such as teamwork and listening.

INTERPERSONAL INTELLIGENCE: Linked to the 'transferable skills' is interpersonal intelligence—the ability to work with one another (Apel, 2017). Apel (2017) emphasised the importance of this particular skill as working as a lawyer requires one to work with multiple parties, and sometimes with lawyers from other areas of practice (Newbery-Jones, 2015; Boyne, 2012).

SOCIAL/ETHICAL AWARENESS: Another important practical skill for law students is ethical awareness (Apel, 2017). The vast majority of studies investigated seemed to comment on this awareness or on the element of professionalism. Closely linked to interpersonal intelligence, professionals must be aware of their ethical responsibilities (Byrnes & Lawrence, 2016; Newbery-Jones, 2015; Waters, 2016; Boyne, 2012).

DEEP LEARNING: Many studies noted the occurrence of deep learning. Factors that affect deep learning include engagement, motivation, enjoyment, and retention. These factors seem to underly many of the pedagogical motivations of the studies and are also apparent in the data collected (Philips, 2012; Widdison et al., 1997; Waters, 2016). Some studies explicitly found that simulation was better at engaging students than traditional methods of teaching (Byrnes & Lawrence, 2016; Daly and Higgins, 2011).

CRITICAL THINKING: Critical thinking was also commonly noted as a benefit of simulation. Due to the active, student-centred nature of simulation, students are encouraged to take on responsibility for their own learning (Philips, 2012; Widdison et al., 1997). This urges students to develop their critical thinking skills, especially when faced with problem situations (Knerr et al., 2001; Boyne, 2012). Boyne (2012) points out how simulations can be designed to maximise student responsibility to replicate the realistic situation of having to find facts and discern their relevance to the case study.

FLEXIBLE DESIGN: The flexibility of simulation design allows for more efficient learning (Byrnes & Lawrence, 2016). Unlike live clinical experiences in which students must advise real clients in real cases, making mistakes in simulations do not have real life consequences (Apel, 2017; Widdison et al., 1997; Waters, 2016). In fact, learning from mistakes can be a useful way for students to learn (Apel, 2017). In open ended simulations, students are able to experiment and learn to think outside the box (Philips, 2012; Widdison et al., 1997). This is particularly useful as unanticipated problems are certain to arise when working in the profession (Widdison et al., 1997).

The limitations of simulation

RESOURCE-DEMANDING: The active role that students must take results in the need for a smaller student to teacher ratio, to allow teachers to facilitate and guide the students' learning (Apel, 2017). Apel (2017) also notes the need for space, equipment, and a convenient timetable. In one study, student feedback indicated that there was not enough time for the students to sufficiently engage in the simulation (Byrnes & Lawrence, 2016). Furthermore, both teacher and student must spend a significant amount of time planning for an optimal learning experience (Apel, 2017; Philips, 2012; Widdison et al., 1997; Daly & Higgins, 2011). However, students may not always be willing to take on an active role in planning, negating the potential benefits of simulation (Apel, 2017; Newbery-Jones, 2015).

LACK OF IMMERSION: Immersion is key in achieving deep learning (Waters, 2016), but not all students are able to immerse themselves (Byrnes & Lawrence, 2016). Newbery-Jones (2015) states that this may be caused by a lack of authenticity of the simulation (Daly & Higgins, 2011). Authors speculate that this may be due to the 'fixed' nature of the pre-designed problem scenarios and its 'desired' outcomes (Philips, 2012; Parsons, 2017; Widdison et al., 1997). Others believe that it may be caused by an incompetency of the designer (Widdison et al., 1997; King, 1974).

Implications of technology

Not all applications of technology improve the simulation learning experience (Maharg, 2017). Newbery-Jones (2015) explains how Resnick (2002) criticised uses of technology where it simply acted as a new medium for traditional teaching methods. Newbery-Jones (2015) concludes that in order for optimal use of technology in education, its use must be carefully planned in accordance with the learning outcomes and tasks at hand. Some technological advances such as the implementation of lecture recordings have caused concern (Elphick, 2018). Rather than improving the learning experience, some law lecturers believe that the use of recorded lectures actually lowers class attendance, leading to further negative consequences (Elphick, 2018).

Furthermore, assimilation of technology must ensure that it does not affect the key factors that contribute to effective learning. In Newbery-Jones' (2015) study, it was indicated that although the implementation of technology was successful, a deficiency of guided reflection took away from the learning experience. Reflection plays a key role in simulated learning and is generally accepted as the distinguishing factor between simply 'having an experience' and 'learning from experience' (Newbery-Jones, 2015).

Despite these considerations, technology seems to overall enhance the simulation experience by adding a "layer of intrinsic motivation" (Widdison et al., 1997) that immerses and engages the participant. It also allows for the creation of a rich and tailored problem space for further engagement (Apel, 2017; Widdison et al., 1997).

Critique of sources

Some sources did not include their collected data or methodology (Newbery-Jones, 2015; Parsons, 2017; Knerr et al., 2001; Boyne, 2012). Others did not make explicit their theoretical/pedagogical evidence and arguments (Byrnes & Lawrence, 2016; Knerr et al., 2001). Although there are many different law modules with different learning objectives, the majority of studies were based on either one or two modules and so had their limitations. Some sources were published in a time when technological innovations were limited but were deemed relevant in their reviews of simulation (Widdison et al., 1997; King, 1974).

3.2 Virtual Reality in Education

Applications of educational VR

In a systematic review conducted by Kavanagh et al. (2017), it was found that there were four main applications of VR: namely simulation, training, accessing limited resources and distance learning. Simulation includes the use of VR to create realistic situations that would be impossible, inconvenient, or too dangerous to experience in the real world (Kavanagh et al., 2017). The 'training' category is similar to the 'simulation' category and indeed are not mutually exclusive, involving the practice and repetition of situations that assist in developing practical skills (Kavanagh et al., 2017). Accessing limited resources is particularly useful when there are financial or spatial restrictions and the virtual space allows for the sharing of information, regardless of physical and spatial boundaries. (Kavanagh et al., 2017).

Emergent themes in educational VR

IMMERSION: Using VR enriches the learning experience by providing realistic and authentic situations (Yeh & Wan, 2016; Aczel, 2017; Pantelidis, 2009) through stimulating visual, aural, emotional, and social effects (Yeh & Wan, 2016). The interactive and immersive nature of educational VR encourages active participation and engages the user (Ludlow & Hartley, 2016; Parong & Mayer, 2018; Yeh & Wan, 2016). Parong and Mayer (2018) explains how students generally work harder when they develop an interest in their learning material. These factors contribute to the increased motivation of users (Parong & Mayer, 2018; Margitay-Becht, 2016; Yeh & Wan, 2016) which in turn leads to improved learning (Kavanagh et al., 2017).

DEEP LEARNING: Kavanagh et al. (2017) notes that increased immersion also leads to deeper learning. Studies have shown a positive correlation between deep learning and enhanced knowledge retention (Margitay-Becht, 2016; Fealy et al., 2019). The use of VR also seems to be effective in the learning of practical skills (Ludlow & Hartley, 2016; Fealy et al., 2019) as well as soft skills such as confidence (Yeh & Wan, 2016). Furthermore, the collaborative capabilities of VR allow for increased enjoyment, improved interpersonal skills and the opportunity for cross-cultural learning (Ludlow & Hartley, 2016; Pantelidis, 2009; Yeh & Wan, 2016).

DESIGN: The flexibility of VR design allows for the creation of authentic and relevant scenarios through enhanced environmental stimuli (Pantelidis, 2009; Sala, 2016). Furthermore, VR creates a safe environment that negates the consequences of mistakes (Sala, 2016; Poeschl, 2017; Aczel, 2017) which allows students to learn further through repetition and experimentation (Margitay-Becht, 2016; Pantelidis, 2009). VR is also suitable for addressing the preference of the current generation of students towards the use of digital technologies (Ludlow & Hartley, 2016). The nature of VR also facilitates personalised learning, allowing students to learn at their own pace for optimal learning (Kavanagh et al., 2017; Pantelidis, 2009; Parong & Mayer, 2018).

IMPROVED SIMULATION: Fealy et al. (2019) suggests that VR improves the traditional simulation experience, both in terms of resource cost and learning. In a study investigating the use of VR in nursing and midwifery education, Fealy et al. (2019) found that VR may address the joint problem of increased student numbers and fewer clinical placements.

Limitations of educational VR

COST OF EQUIPMENT AND TRAINING: Although the cost of using VR has recently decreased (Merchant et al., 2014), it remains a significant concern. Many studies comment on the heavy financial investment of initial purchase of the equipment (Merchant et al., 2014; Baxter & Hainey, 2019), as well as the ongoing cost of its maintenance and support (Kavanagh et al., 2017). Furthermore, new users are likely to find difficulty in the operation of the hardware, and so time must be taken to train both students and staff (Ludlow & Hartley, 2016; Pantelidis, 2009; Aczel, 2017). Technological complications will also require the need for a technician (Yeh

& Wan, 2016). Furthermore, Yeh and Wan (2016) warn of the significant workload that must be anticipated when using VR as a teaching method.

HARDWARE: Although VR technology has advanced substantially, studies indicate a lack of realism due to the physical limitations of the current hardware (Ludlow & Hartley, 2016) which may cause a lack of engagement (Kavanagh et al., 2017).

DESIGN: This limited hardware inevitably limits the design of VR environments in learning. According to the coherence principle, excessive use of unnecessary features may create irrelevant cognitive processing in the learner's mind, interrupting the cognitive learning process (Parong & Mayer, 2018). Therefore, educational VR must be designed with clear learning objectives (Yeh & Wan, 2016), especially because the ability to design VR does not necessarily require pedagogical knowledge (Aczel, 2017).

HEALTH ISSUES: A few studies also revealed a number of health-related concerns, including motion sickness, eye strain and dizziness (Baxter & Hainey, 2019; Aczel, 2017; Pantelidis, 2009).

Critique of sources

Many studies made little or no mention of pedagogy (Margitay-Becht, 2016; Fealy et al., 2019; Merchant et al., 2014; Poeschl, 2017). A number of studies were solely focused on specific areas of education and thus the results may not be generalisable (Yeh & Wan, 2016; Parong & Mayer, 2018). However, the sources generally had clear descriptions of methodology and data when presenting results.

3.3 Learning Theories

Simulation learning theories

EXPERIENTIAL LEARNING: A significant number of studies employ Kolb's (1984) experiential learning theory. This theory presents a four-stage learning cycle of concrete experience, reflective observation, abstract conceptualisation, and active experimentation (Kolb, 1984). Kolb (1984) states that learning begins with an experience and happens in the reflection and conceptualisation process. Experience guides and informs future experiences, making it a useful tool in the acquisition of skills (Waters, 2016; Newbery-Jones, 2015). Parsons (2017) argues that learning how to reflect upon one's experiences is crucial in developing an ability to self-critique and improve, which is especially valuable in the face of a rapidly changing legal profession.

PROBLEM-BASED LEARNING: Problem-based learning (PBL) presents the learner with a problem question and the learner must apply their knowledge to find a solution (Daly & Higgins, 2011). Applying this in the context of mooting, students must not only be able to contextualise their substantive legal knowledge, but they must also convincingly build and argue their case (Daly & Higgins, 2011). Philips (2012), however, warns that the facts that form pre-designed problem scenarios will not necessarily be conveniently found or readily presented in reality, and that the use of PBL may discourage the ability to think outside the box.

SITUATED LEARNING: With the growing technological possibilities of creating virtual environments, simulations have begun to encourage learners to learn more from their role and surroundings (Maharg, 2017; Thanaraj, 2016). Situated learning states that learning takes place in the social context through being integrated into a situation (Vygotsky, 1978). Newbery-Jones (2015) designed a virtual environment in which students could work through a legal case load with other students. This allowed the students to improve their legal knowledge and practical skills, but also to work on other skills such as professionalism and collaboration with other non-legal entities (Newbery-Jones, 2015). This form of learning has gained popularity as it enables the learning of both practical skills and ethical/professional conduct (Newbery-Jones, 2015).

Other pedagogical motivations

TRANSFORMATIVE TEACHING: Elphick (2018) introduced the concept of transformative teaching—transforming the learning experience by implementing dynamic interactions with the aim of engaging and motivating students. Five elements of transformative teaching are presented: active, student-centred, collaborative, experiential, and problem-based (Elphick, 2018). Interestingly, a survey of student preferences of the five categories of transformative learning showed that PBL was the most popular with experiential learning being the least popular (Elphick, 2018). However, it must be noted that the students were not given detailed explanations of the forms of learning and were only presented with two limited examples of each category.

OTHERS: In Thanaraj's (2016) review, two other theories are identified. Expansive learning through activity involves a group of learners expanding a learning activity to transcend its original learning objectives and go further through cooperative rethinking and reconceptualization of the activity (Engestrom, 2003). Marton and Saljo's (1976) theory on deep learning states that students experience deep learning and meaningful understanding when they actively engage and interact with the learning material. These theories were not prevalent in the literature, and so are not discussed further.

Educational VR learning theories

A frequent limitation identified in many of the studies in this area was the lack of pedagogical reasoning and evidence. Many of the studies that did not explicitly mention a particular learning theory or pedagogical reasoning seemed to imply the use of learning theories (Fealy et al., 2019; Merchant et al., 2014; Margitay-Becht, 2016). In the sources that did explicitly mention their pedagogical reasoning, the following five theories were used.

CONSTRUCTIVISM: Based upon Dewey's (1985) learning model, constructivism states that people construct knowledge by actively interacting, discovering, and creating ideas. Many educational VR learning tools are built upon this constructivist theory (Ludlow & Hartley, 2016). This is because VR is ideal for constructive learning as it encourages and allows the user to actively engage and interact with various people and objects in a relevant context (Pantelidis, 2009; Aczel, 2017).

EXPERIENTIAL LEARNING: Although Elphick (2018) found that experiential learning methods were the least popular amongst students in legal education simulation, Baxter and Hainey (2019) found that in the context of VR, experiential learning was the most popular.

SITUATED LEARNING/COLLABORATIVE LEARNING: The use of VR often involves the collaboration of multiple users. In a study on using VR to teach foreign languages, Yeh and Wan (2016) found that discussion and interaction between learners facilitated additional meaningful and effective knowledge construction. Ludlow and Hartley (2016) found that learners enjoyed the opportunity to work with others. Situated learning is also widely used in educational VR (Aczel, 2017). Yeh and Wan (2016) noted that the opportunity to interact with native speakers through VR not only helped with their language skills, but also with developing a sociocultural awareness of the different cultural attitudes that was useful in promoting more effective communication.

ACTIVE LEARNING: Ludlow and Hartley (2016) states that encouraging active participation of learners through interaction with objects and people engages and motivates the user. It was found that the intentional implementation of numerous interactions within the virtual environment made the experience enjoyable and immersive (Ludlow & Hartley, 2016).

GAMIFICATION: Gamification is the implementation of game-like characteristics into educational contexts (Kavanagh et al., 2017). Features such as a narrative plot, objectives, rewards, and character development enhance immersion and hence engagement (Merchant et al., 2014). In a comparison of non-immersive game-based VR, VR simulation and virtual worlds, Merchant et al. (2014) found that students generally performed best in game-like contexts.

4 Discussion

4.1 How Has Simulation Impacted Learning in Legal Education, and How Has the Use of Technology Changed Simulated Learning in This Context?

Legal education has long been criticised for its overly academic focus and its failure to adequately teach necessary practical legal skills and ethical awareness (Susskind, 2013). Upon review, the increased assimilation of various forms of simulation as a pedagogical tool has been greatly beneficial in addressing this problem. There are, however, limitations to its effectiveness.

Simulation is very demanding in terms of time and resources. Effective simulations must be well designed by professors and well prepared for by students. There must also be facilities and time available for the simulation to take place. A lack of authenticity of the simulation often results in a lack of immersion, preventing deep learning and optimal learning.

Attempts to tackle the problem of authenticity using technology seems to have succeeded to an extent (Maharg & Nicol, 2014) but the resource-demanding nature remains unsolved. Most recently, non-immersive virtual environments have been developed to increase immersion and engagement and can currently be seen as the most advanced form of simulation in terms of technological capability in legal education (Thanaraj, 2016). Nevertheless, other disciplines have already employed more advanced forms of technology such as immersive VR (Kavanagh et al., 2017), indicating that there is still room for improvement in legal education.

Not all uses of technology, however, are effective. In order for it to be useful, technology must be implemented together with intentional and carefully planned learning objectives and goals. It is also imperative that the focus on technology does not disrupt the key factors that contribute to effective learning.

4.2 What Has Been the Impact of Virtual Reality Technology in Education?

VR has recently gained popularity in education due to its wider availability and its suitability to facilitate pedagogical methods. The literature shows that VR has very similar benefits to simulation in legal education. It is indicated that VR may be an improved form of traditional simulation, but the empirical evidence is very limited.

VR also has its limitations. The price of buying and maintaining VR technology is still quite high, and new users must take time to get used to its operation. Although VR can provide a fully immersive experience, it still has its physical limitations in terms of realism. Furthermore, some studies reported health concerns.

Parong and Mayer (2018) warns that the use of educational VR must also be carefully planned with clear learning objectives and goals, as excessive features may divert the learner's cognitive processing from the important material.

4.3 What Pedagogical Motivations and Theories Underly (A) Simulation in Legal Education; and (B) Virtual Reality in General Education?

Both bodies of knowledge are lacking in solid pedagogical and theoretical foundations. Although both are used as pedagogical tools used to inform pedagogical practice, little or no mention of the underlying theoretical basis is mentioned in the majority of studies. From the review of the studies that do, it seems that there is significant overlap. Depending on the learning objectives and design of the activity, different learning theories must be employed according to its suitability for the role.

5 Conclusion

Theoretical implications—It is clear that both the use of simulation and VR require careful and learning objective-oriented design in order for it to be an effective teaching tool. This means that the design must be rooted in and formed around pedagogical theory. However, this review has revealed that the majority of studies do not do so.

Practical implications—Fealy et al. (2019) suggests that using VR could be the answer to the decreasing number of clinical placements in the nursing and midwifery context. This is because VR can create clinical/experiential opportunities that can be used by students in their own time and space. Applying this to the legal simulation context, VR may have the potential to at least partially address the need for a convenient space and time. There is also theoretical and empirical evidence which suggests that VR could act as an enhanced form of traditional simulation in its ability to immerse.

Although VR technology has practical and physical limitations, this review has revealed theoretical evidence that the implementation of VR may potentially enable traditional forms of simulation to go beyond their current limitations in education. Further empirical evidence rooted in strong pedagogical theory and design is needed.

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The Use of VR Simulations in Nuclear Physics Education at the University Level

Predrag Šiđanin, Jovana Plavšić, Ilija Arsenić, and Miodrag Krmar

Abstract The use of virtual reality (VR) in the education of nuclear physics students, at the university level, is very rare. This paper aims to present the result of a nuclear physics exercise designed to compare real-world exercise ability (mass of Deuteron's experimental setup available at the Faculty of Physics) with simulated exercise in VR. Students perform all the functions virtually at the human, atom and subatomic particles scale, in a radiation-free environment and time-saving manner. This research is beneficial for universities that do not have the appropriate equipment to perform nuclear physics exercises.

Keywords Education · Nuclear physics · Exercise · VR · Oculus rift · 3D simulation

1 Introduction

In the last couple of decades, virtual reality technology (VR) has created new opportunities to support the education process. VR technology significantly changes the teaching process, forming new models of education and adding a new relationship

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structure between teachers, students, and the media. This additional education environment is an effective way of improving educational performance whilst simultaneously promoting modernization in the education infrastructure (Zhang, 2017). VR techniques support the concept of 'teaching with pleasure', they stimulate and motivate users with immersive virtual reality experiences. Teachers and students interact with educational content in a virtually generated 3D environment. VR technology could visualize, simulate, and reproduce processes and natural phenomena that can otherwise not be observed in such detail. It could help students to understand the complexity of abstract phenomena using concrete images and providing students with more intuitive and dynamic learning processes. This new teaching technology provides a dynamic and realistic simulation of a phenomenon or process, without fear of damage to equipment or bodily injury (Li & Wu, 2006). In a virtual environment, a student can experience direct interactions with the learning environment and receive interactive feedback, which makes for a strong sense of presence in the learning process. Also, students could completely break the limitations of space, from the observation of cosmic structures or celestial bodies down to the scale atomic particles. Students could enter the interior of these objects to make observations. They could also break through the limitations of time. Some dynamic processes which take decades or even hundreds of years to observe could be presented to students in a short period of time (Liang, 2006). VR technology changes the form of learning, from passive into active learning, where the virtual classroom became a dynamic platform for teachers and students to actively participate, interact and develop together (Miao et al., 2018). Active dialogue and participation between teachers and students, which is the basis of the education process, should be considered in the design of new educational tools (Feenberg, 2005). These new educational tools involve programming and development, interaction design, interface design, teaching content design, scene modeling as well as many other diverse fields, knowledge, and skills. It also requires the cooperation of researchers from a multitude of scientific and technological sections (Chang et al., 2018). Although VR is only in the initial development phase for applications in education, it already offers great opportunities and breadth of use.

The application of virtual techniques and especially virtual reality (VR) in physics will be analyzed in this paper from the perspective of the ability to modernize the teaching of nuclear physics, especially in the experimental part, which requires the active participation of students. Although virtual reality is welcome in all areas of physics, there are several specific reasons why experimental teaching in the field of nuclear physics can be considered as a good area for the application of VR (Fig. 1). For example, for competent experiments in nuclear physics, it is necessary to possess sophisticated and expensive equipment. With simple equipment such as GM counters, it is possible to design a number of experiments for basic nuclear physics courses. However, a lot of units in the standard nuclear physics curriculum, concerning radiation spectroscopy, nuclear properties, and interactions, nuclear reactions, etc. require technical resources that a larger number of universities cannot afford.

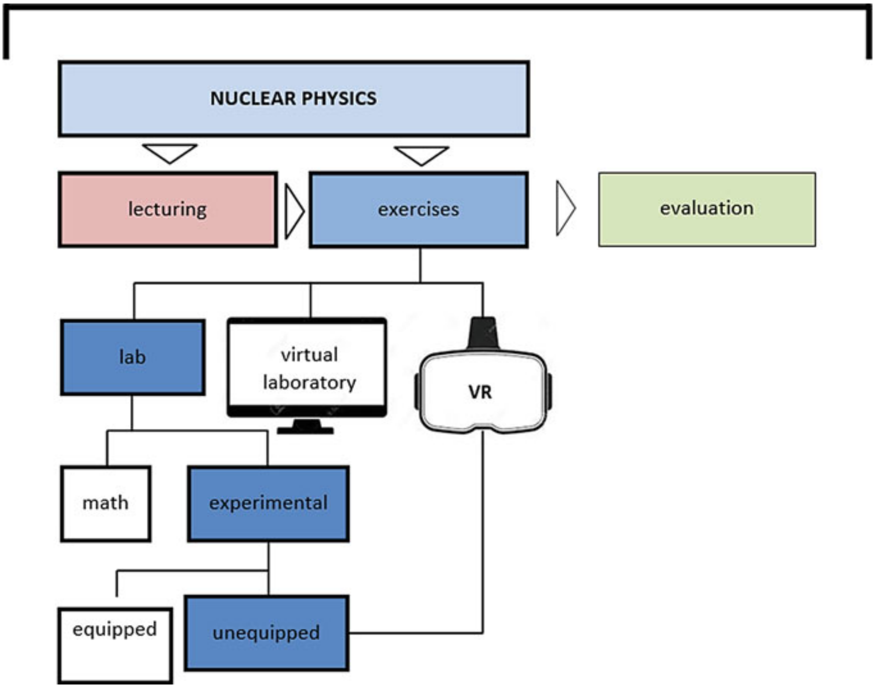

Fig. 1 Position of virtual reality (VR) in nuclear physics teaching

2 Related Work

Emerging technologies, such as virtual and augmented reality, have been recognized as powerful learning aids in formal physics education. Studies have shown that these technologies help students in the knowledge grasping process, as they make abstract concepts more comprehensive (Kaufmann & Meyer, 2008; Savage et al., 2010). Moreover, students who used immersive technology in the learning process achieved superior academic results compared to those who were taught in a traditional classroom setting (Kim et al., 2001) and performed better in the long-term retention tasks (Brelsford, 1993; Fidan & Tuncel, 2019). Virtual reality simulations have been applied in branches of physics in higher education (Demaree et al., 2005; Franklin & Ryder, 2019) and secondary education (Bogusevschi et al., 2020). However, up to date, the examples of the application of VR/AR technologies in the domain of nuclear physics at the university level are rare. Our work presents an attempt to improve the nuclear physics education by providing a framework that is easily replicable in visualization problems of different experimental setups.

Even though augmented reality (AR) has shown potential for physics training and teaching (Dünser et al., 2012; Hruntova et al., 2018), we have chosen to use VR in our simulation, because it allows physical movement, direct interaction with the content and greater level of immersion. Research has shown that movements and gestures are beneficial for the understanding of abstract concepts (Kontra et al., 2015) and that a higher level of embodiment results in better knowledge acquisition (Johnson-Glenberg, & Megowan-Romanowicz, 2017). Navigation and object manipulation in our virtual reality simulation is realized through the use of controllers.

In recent work, Greenwald et al. (2019) have presented ElectroVR, a promising shared learning space for physics education and research that combines collaborative learning with embodied learning in immersive six degree of freedom VR environment and simulation-based exploratory learning. The instructor and learners coexist in the virtual space, transforming the traditional teacher-centered system, while still preserving their roles. Our work does not support a multi-user environment, but our experimental setup is tailored for individual experiences and the interaction with the content is restricted to one person at a time. Although collaborative space is a clear advantage, it is not relevant for our specific use case.

3 Methods

A new strategy for the use of computer technology in nuclear physics education, at the Faculty of Physics, is the use of virtual reality (VR) simulation. The 3D immersive VR-based educational application simulates real-life nuclear physics exercises in a radiation-free environment. Providing students with repeatable exercises, which allow them to see "the invisible", providing them with immediate feedback and data visualization. The main purpose of these simulations was to present the importance and capabilities of virtual reality as an innovative computerized teaching strategy.

The strategic plan is to implement, in a VR environment, exercises that cannot be done in the laboratory due to technical capability limitations. It is envisioned that a set of ten such exercises will be created, and this text will show the first pilot realized exercise 'The Mass of Deuteron'. This pilot exercise was designed to compare real-world exercise capabilities (the mass of the Deuteron experimental setup available at the Faculty of Physics) with the simulated exercise in VR. One of the benefits of this exercise is that the student can see what cannot be seen in the laboratory, i.e. what goes on inside the experimental environment at the atomic and particle scales during the radiation process. This, as well as other exercises, foreseen for future realization in VR, is intended for all educational institutions whose laboratories are not equipped to perform this type of experimental exercise. The relationship between exercises in an equipped and unequipped laboratory where VR simulations can be used is shown in Fig. 2. This strategy completely recreates these nuclear physics exercises, in institutions where these experiments out of physical reasons (lack of equipment and similar), cannot be performed.

To realize this strategy, cooperation with the EduVRlab (the virtual reality laboratory from the Faculty of Digital Production) at University EDUCONS of Sremska Kamenica, was established. The lab is equipped with high-quality virtual reality devices. In addition to education, this laboratory is also engaged in research concerning various domains of visualizations and simulations using immersive

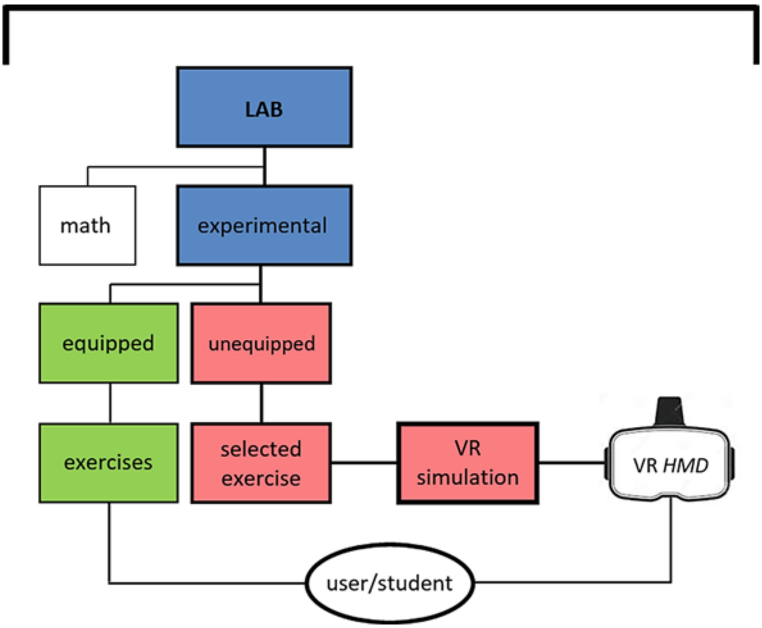

Fig. 2 Scheme of the relationship of an experimental exercise in an equipped and unequipped nuclear physics laboratory

virtual reality (Sidjanin & Plavsic, 2019). To design the pilot exercise 'The Mass of Deuteron', a variety of software was used. Modeling, and animation were done in 3Ds Max, Photoshop was used for texturing and for the simulation in virtual reality we chose Unity 3D and some coding in C#. The simulation was done according to a well-defined procedure to perform the validation of the exercise. This, in turn, ensures that the students have the most realistic experience while interacting with the virtual environment. The experience of the virtual environment is enabled by VR equipment. The head-mounted display (HMD) Oculus Rift was used for the VR visualization and simulation of data for this exercise. The Rift is equipped with a pair of OLED (Organic Light Emitting Diode) screens, with an 110° field of view and with six degrees of freedom (6 DOF). Due to the consideration of the specificity and potential of the exercise, we have decided to navigate with the pair of the Oculus controllers. In approximately 5 min, the student can access all the procedures in the exercise. The simulation enables intuitive navigation and comprehension of the virtual environment completely naturally and freely, with the possibility of observing the setup in great detail, especially on the scales of microcosms or particles. This is a considerable benefit of VR technology which enables any interested party to use this type of stimulation for the exploration of specific phenomena. Figure 3 presents the workflow of the VR visualization and simulation of the selected exercise.

'The Mass of Deuteron' exercise can be divided into two simulated realities: visible reality and invisible reality. The *visible reality* is the one that the student

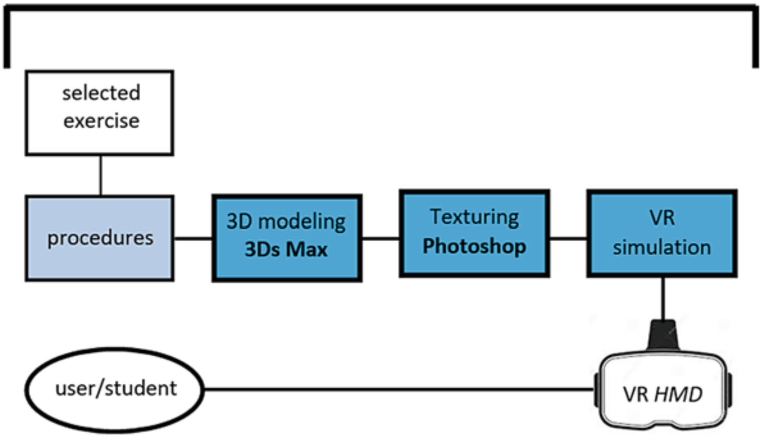

Fig. 3 The workflow of VR visualization in 'The Mass of Deuteron' exercise

experiences based on his or her previous experience in the laboratory, their interaction with the equipment that the laboratory is equipped with, the elements of the interior, and the sample being tested. These are all objects that are present in the virtual scene. Some of these objects are 'active', which can be manipulated via the controllers (captured, moved, transmitted, etc.) or animated, such as the chamber with a device inside, where this experimental exercise takes place. The containment chamber can be opened or closed by pressing certain controller buttons. Most of the other elements that fill the lab space are not active objects for VR manipulation since they are not relevant to the exercise procedure. The *invisible reality* is one that the student is otherwise unable to see and is beyond his real experience. This reality is located inside the closed containment chamber. The student also encounters for the first time the process of conducting an experiment at the atomic or even smaller scale, such as the scale of fundamental particles. Figure 4 shows the process of performing the exercise in VR from start to finish, in both visible and invisible reality.

4 Results

The results of the VR simulation of the exercise itself looks like this: the assistant introduces students to the exercise they will undergo in virtual reality. At the very beginning, students are given basic instructions on where to stand, where the sample is, and how to take it and place it in the chamber, which needs to be opened beforehand. Also, they are instructed on how to use the controllers in order to navigate and manipulate objects. Each learner is then helped to a comfortable position with the HMD on the head, given the controllers and the application is launched. At the beginning of the virtual experience, the student has an overview of the entire virtual laboratory, shown in Fig. 5. The student is free to move around and to explore the

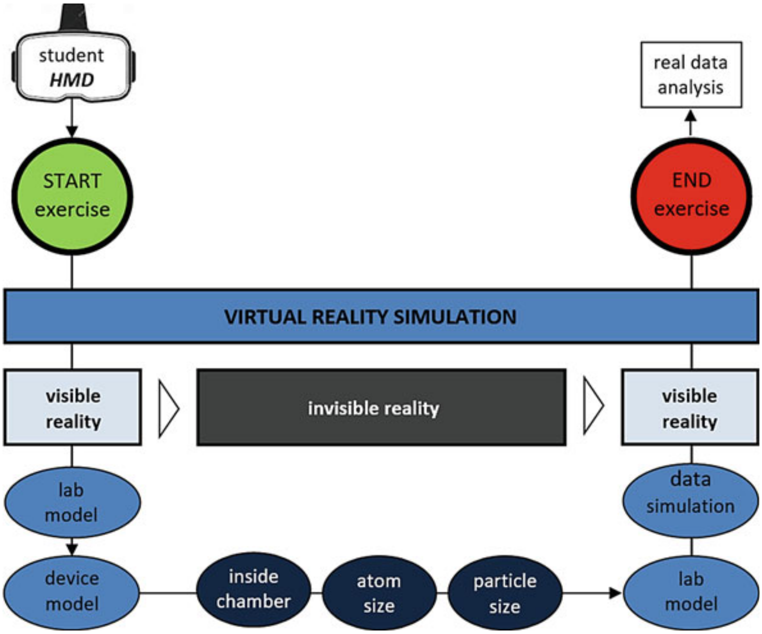

Fig. 4 Workflow from the start to the finish of the exercise through *visible* and *invisible* reality

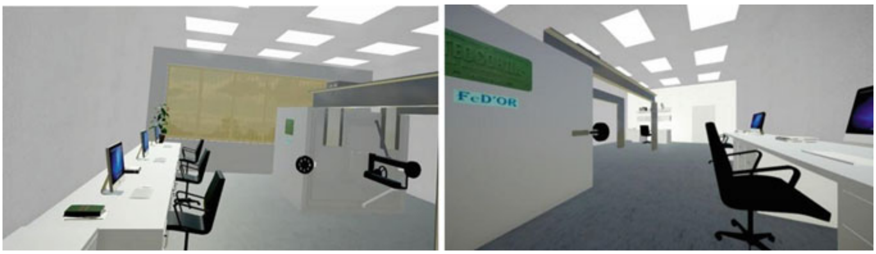

Fig. 5 The appearance of the laboratory at the beginning of the exercise and during its exploitation

virtual laboratory and view it from different angles, from an average height of about 175 cm. The assistant observes all student actions in the virtual environment on the computer screen.

Next, the student needs to push a specific button on the controller to open the chamber containing the device used to perform 'The Mass of Deuteron' exercise. This activation triggers an animation within virtual reality and the student sees the protective flywheel open, the reels start turning and the heavy door of the device's protective chamber opens, Fig. 6.

When the chamber is open, it is ready to have a test sample inserted. The student then goes to a desk with a sample box, and using the controllers takes it into the virtual

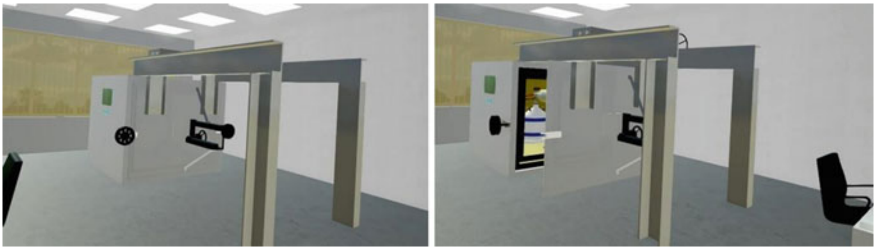

Fig. 6 A closed and fully open chamber into which the test sample is placed

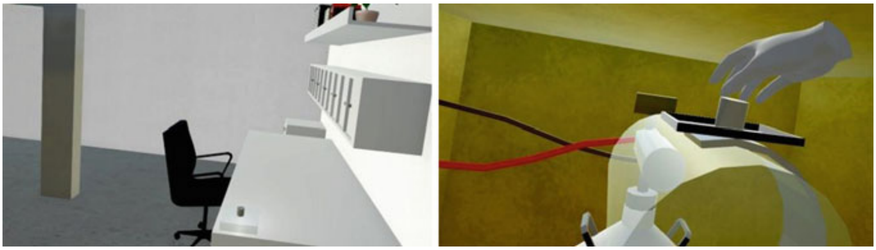

Fig. 7 The table with the sample and the sample positioned inside the device

avatar's hand, brings and puts it in the correct position within the device's protective chamber, Fig. 7. Placing the sample at the correct position requires a certain amount of skill, so it is possible to repeat this action several times until the student becomes familiar with the controls.

When the sample is correctly positioned, the student moves away from the chamber door and closes the chamber via animation by pushing a specific button on the controller. The device is then ready to start analyzing the sample. It reads and records the data for analysis. The student also initiates the start of the entire analysis process via a button on the controller. Then the student can 'enter' a 3D virtual space, otherwise invisible, the point of view travels inside the closed chamber and it is possible to examine the interior, measuring devices, water container, and a sample box. Next, by pressing a particular button on the controller, students 'enter' deeper, down to the atomic scale where they can examine the structure of the hydrogen atoms and observes their spatial movements. These two invisible actions are illustrated in Fig. 8.

The next invisible level which a student can explore in the virtual environment is on the scale of subatomic particles, where the interactions of hydrogen nuclei (proton) with thermal neutrons are simulated. In that particular moment when the particles touch each other, a spark of light—photon is created. These processes in which a photon is created are next to impossible for students to perceive, Fig. 9. If students continue to look at the deuterium nucleus created, they can see that the spheres exchange color, which would correspond to the exchange of charged meson.

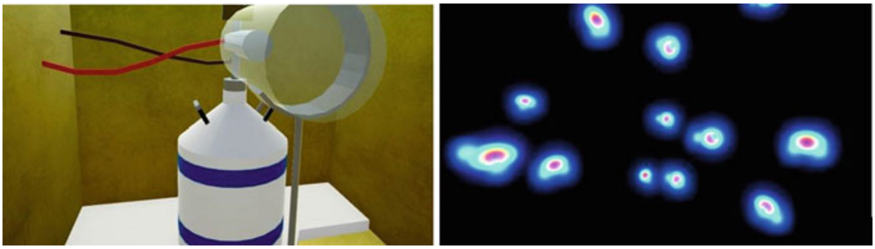

Fig. 8 The view inside the closed container and the structures of a hydrogen's atoms—the level of the microcosm

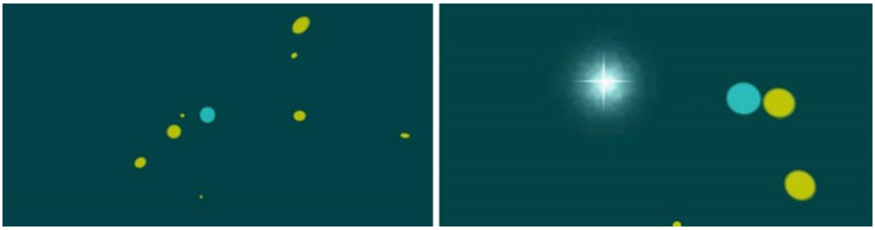

Fig. 9 The view representing the structure of hydrogen and radioactive particles and obtaining photons by coupling—the level of the particle size

This is the completion of the bombardment process with the decay products of radioactive isotopes. In real-time, the device collects data for a minimum of 12 h, which is reduced in virtual reality to a few minutes for the student to go through this virtual exercise. By activating a particular button on the controller, the students exit this invisible reality and returns to the virtual laboratory, where they can see an animated spectrum of the data collected displayed on one of the computers, Fig. 10. After viewing the spectra the virtual exercise is completed and the students take off HMD set from the head and finds themselves again in the real laboratory. There, in the real laboratory, on the computer, the student can see real collected data, which assistant prepared. Further, the student analyzes collected data from real sources to successfully complete this exercise.

Fig. 10 Simulated spectral data acquisition results visualized in VR

As previously noted, this VR simulation is a pilot-project of a particular exercise (the mass of Deuteron), to demonstrate the applicability of virtual reality technology for the nuclear physics university education. The desired outcome is achieved. Modeling of the virtual environment was done first—a laboratory with a chamber that measures and collects data for the specific exercise. Additionally, we realized the student interaction with the measuring device and the sample for which the data is collected. This was done realistically, based on the existing nuclear physics laboratory. The benefit of this exercise, apart from the established protocol, is that the student can view the process inside the chamber, which is physically not feasible in the real lab. The student is observing the process inside the chamber in a safe VR environment, without being exposed to radiation. Furthermore, the process of colliding the particles on an atom level, and even smaller subatomic particles can be seen. This procedure provided a unique experience for the student, which would have never been possible in the real lab environment. After removing the HMD set, now using the regular computer screen, the student can view pre-prepared and previously collected data for a specific sample for which the measurement was made, so that it can be immediately continued with its further process of analysis and evaluation. Each student completes the exercise in approximately 5 min, while it would take over 12 h only for data collection in the real laboratory. The number of repetitions and the length of the experience for individual students are not limited. Each repetition is a completely identical protocol. What is achieved by this exercise in the virtual environment? The given results indicate next:

- Realistic modeling and simulation of any exercise are necessary for nuclear physics education on the university level, by following the presented methodology;
- All VR exercises need to be monitored and coordinated with real protocols and information, for accurate and realistic simulations;
- There is an unlimited number of possible simulations of those exercises to educate students at universities without adequate equipment for their physical, realistic performance;
- There is a need for collaboration and networking of different university nuclear physics laboratories and the exchange of detailed information on devices, protocols, and data collected, for the realization of fully realistic VR modeling and simulation, to maintain successful exercises in a virtual environment;
- It is possible to repeat the exercise with the same quality and at any time and place, with the appropriate VR setup;
- Exercises held in a virtual environment significantly reduce costs, compared to the existing laboratories. This also allows the students to complete the exercise individually, rather than as a group, which is the current practice.

This demonstrates the considerable benefits of maintaining exercises in the virtual environment of nuclear physics, compared to the classical methods of education. A next planned step in the research is to form the set of 10 nuclear physics exercises, which requires cooperation with other universities. As this is a pilot simulation of just one of the exercises, qualitative analysis of its use is not possible. This was not the aim of this research. The next step in nuclear physics education would be to visualize some of the theoretical fundamentals because its abstraction can be problematic for students to visualize. Thanks to virtual reality technology, many of the theoretical concepts could be visualized and explained.

5 Conclusions

This paper presents one possibility of using the virtual reality technique in performing the experimental part of teaching in the field of Nuclear Physics. In a relatively simple experiment, it was shown how by combining VR and the real data obtained in one laboratory, students at universities having no appropriate infrastructure can become familiar with experiments. By combining VR and real data, the basic goal is achieved: to get students acquainted with one concept in Physics (in this case it is the binding energy and mass of Deuteron). However, a very significant potential of VR experiments is that students can get a 3D visual presentation of objects or processes that are beyond the level of human perception, as objects or processes in the world of atoms, nuclei, and particles. The same technique can be used to show students parts of experimental setups where the observer cannot enter. In the experiment presented in this paper, the possibility that the VR technique could show some processes to be accelerated was used. Some of the very short-lived processes, such as neutron capture at the nucleus of hydrogen, can be displayed in slow motion using VR techniques. This paper presents a combination of VR and real data in the field of Nuclear Physics, although a similar way of organizing students' exercises can be applied in all other experimental disciplines.

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Creating Memories and Engagement in College Student Through Virtual Reality

Sandra Maria Correia Loureiro, Ricardo G. Bilro, and Fernando Angelino

Abstract This study intends to extend the understanding of drivers of student engagement in the educational context and analyse mindfulness as a moderator of the different associations in the proposed model. The proposed model regards VR experiences as stimuli, telepresence, pleasantness of the experience and memory as an organism and student engagement as the response. A sample of 136 participants allowed us to test the model. Findings revealed that all hypotheses were supported except H6 linking pleasantness of the experience with student engagement. Only the relationship between pleasantness and memory is higher for mindful students than non-mindful ones. These findings mean that students do not need to feel pleasure about what they are learning to be engaged

Keywords Virtual reality · Student engagement · Telepresence · Pleasantness of the experience · Memory · Mindfulness

1 Introduction

In higher education environments students are mainly from younger generations who are digital natives (Mulvey et al., 2019) and the use of technologies are becoming a core topic. The current study focuses on the topic of students' engagement in learning environments, which we propose to assess through virtual reality (VR).

The major concern of faculty members—when thinking about the obstacles in their course—is regarded to the level of intellectual challenges needed to master the course content. They expect students to be engaged in learning and think critically

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to overcome the learning challenge. However, students who are not in tune with the true goal of education may not see it this way (Smith-Robbins, 2011). College students tend to consider some current teaching methods as, inadequate and outdated, especially when there is little use of some tools and learning technologies in the "classroom environment" (CIES-ISCTE, 2008). Some lecturers also tend to consider the application of new methodologies as a waste of time, mainly due to an incomplete understanding of them. According to Huang and Soman, (2013), the main reasons for dropouts or low performance include a lack of engagement or boredom, a pattern of growing absenteeism where each absence makes the person less willing to return to classes. How to handle this issue? The use of VR can be part of the answer.

VR has been increasingly implemented as a tool for simulation and entertainment in several industries, for instance, retailing (Krasonikolakis et al., 2014), tourism (e.g., Kim et al., 2018; Tussyadiah et al., 2018) and above all in medical issues (Loureiro et al., 2018).

Several studies are more focused on how consumers experience VR through concepts of engagement, attachment and purchase (e.g., Bilro et al., 2019; Grewal et al., 2017; Itani et al., 2019; Krasonikolakis et al., 2014; Prentice et al., 2019; tom Dieck et al., 2018a, b), where the S(stimuli)-O(organism)-R(response) framework (Roschk et al., 2017) is greatly employed as the basic theoretical background. Therefore, more research is needed to understand how VR experience can enhance college students' engagement in learning. Hence, the current study purposes and validate a model portraying the influence of VR experience on student engagement, extending the S–O-R framework. The contribution of the study is twofold: (i) extending the understanding of drivers of student engagement in the educational context; (ii) analysing mindfulness as a moderator of the different associations in the proposed model.

Virtual reality experience, telepresence, pleasantness of the experience and memory are regarded as drivers of student engagement. Telepresence, pleasantness of the experience and memory are considered as mediators between virtual reality experience and student engagement. Mindfulness is explored as a moderator through a multi-group analysis.

2 Literature Review

The proposed model is founded in the S-O-R framework, where VR experiences are regarded as stimuli. Experiences have been studied through two major conceptualizations: experience economy and brand experience. This last perspective conduct to Schmitt (2009) points out that experiences comprise *sensory, emotional, cognitive, behavioural, and relational value*s. Yet, for Pine and Gilmore (1998), experiences represent the possibility to live in a different situation from the daily routine, being an event, which should be unique and special.

Experiences depend on the consumers, tourists, or students' individual interpretation of the event (Lemon & Verhoef, 2016; Meyer & Schwager, 2007). Therefore, even when two individuals consider that a certain experience made them feel happy, their level of happiness will be felt in different ways. Even more, it is also very unlikely that the experience will be retained in both memories for the same period of time because it depends on the intensity and strength with which it is handled (Lemon & Verhoef, 2016; Loureiro, 2014). Hence, experiences have been associated with behavioural intentions, memories, emotional attachment (Loureiro, 2014; tom Dieck et al. 2018b).

In the current study, the experience lived through virtual reality is expected to influence pleasure and memory creation through telepresence. The concept of telepresence focus on the fact that VR stirs up the sensation of presence, aggregating interactivity, and vividness (Cummings & Bailenson, 2016). Telepresence provides to those who live a certain experience a vivid memory of the place and an illusion that they are invited to be there (Choi et al., 2016; Loureiro et al., 2019a, b, c). A favourable and immersive VR experience will be associated with a sense of being there, a sense that participants are invited to be there. Telepresence is the initial component of organism because it refers to the college students' subjective experience and feelings that are present in VR experience. Therefore, we suggest the following hypothesis:

H1: VR Experience is positively associated with Telepresence.

VR technology may facilitate student engagement thorough telepresence (Choi et al., 2016; tom Dieck et al. 2018a,, b). Telepresence generates an attraction to the place, which in this case is a virtual environment that allows learning (Choi et al., 2016). Pleasantness of the experience represents positive feelings due to the VR experience and the learning process that such technology increments (Kaltcheva & Weitz, 2006). Thus, we formulate:

H2: Telepresence is positively associated with Student Engagement.

H3: Telepresence is positively associated with Pleasantness of the Experience.

As telepresence refers to the use of VR to have the appearance of being present, enriching the experience, then it is expected to contribute to creating memories in consumers' minds. In this vein, we suggest:

H4: Telepresence is positively associated with Memory.

Given that emotions are needed to create memories (Loureiro 2014; Ramkissoon et al. 2013), we argue that a virtual experience generates a sensation of pleasure in students will influence the creation of memories. The following hypothesis is proposed:

H5: Pleasantness of the Experience is positively associated with Memory.

Student engagement is the main outcome proposed in the current study. The pleasure of being in a VR environment may develop in students a motivation to be more cognitively, emotionally and behaviourally open to learn (Criado & Such, 2011; Isiaq & Jamil, 2017). We suggest that:

H6: Pleasantness of the Experience is positively associated with Student Engagement.

As emotions contribute to generating memories and may develop the motivation to be engaged, memories of positive events are vehicles that lead students to repeat the experiences and keep them motivated and open to learning more (Itani et al. 2019; Loureiro 2014). We propose:

H7: Memory is positively associated with Student Engagement.

The way students live the VR experiences, feel emotions, create memories, and become more or less engaged in learning may be moderated by the extent to which students are mindful. Mindfulness has been regarded as a state of mind and connected to situational factors and intrapersonal traits (openness to novelty, sensitivity to different places and contexts, awareness of multiple opportunities, possibilities or perspectives, and more receptive attention to current experiences) (Langer & Moldoveanu, 2000; Loureiro et al., 2019a). Mindful individuals tend to be more open to new information, have a greater sensitivity to the environment and create new categories in memory that allow them to structure their perceptions in a way that they are more effective in problem-solving (Loureiro et al., 2019a; Loureiro et al., 2019b). Mindful people have high sensitivity and awareness of the environment and pay attention to the current experience (Brown et al., 2007). Mindfulness influences individuals' cognitive, affective and behavioural responses (e.g., Bishop et al., 2004; Kabat-Zinn, 2003; Loureiro et al., 2019b).

The current study follows the perspective of the Langer Mindfulness Scale (LMS) (Langer, 2004), which comprises four domains: novelty-seeking (represents a student who perceives any experience as an opportunity to learn something new), engagement (the students' ability and willingness to notice details about their experience and relationship with the environment), novelty producing (describe students that generates new information to understand the current experience), and flexibility (the tendency to accept a change that come from the environment) (Loureiro & Fialho, 2017). Hence, mindfulness would suggest that the student's degree of mindfulness influences the favourable effect of VR experience on telepresence, pleasantness of the experience, memories and even student engagement. The focus on the stimuli of the moment (through the experience using VR) and the flexibility to be open to new experiences of more mindful students may strengthen the relationship among the constructs in the model than in the case of less mindful students. Thus, the following hypothesis emerges:

H8: There are significant differences in the relationships between latent variables in the structural paths between less mindful students and mindful students.

3 Methods

The experiment took place in a room used solely for the experiment, and with a spacious area for the installation and setup of the equipment. In terms of equipment installation, the only specific requirements were those related to the VR headset model (Oculus Rift), which requires specific steps to be taken to adjust the viewing

Table 1 Sources of the constructs of the questionnaire

Construct	Source
VR experience (dimensions: aesthetics, education, entertainment, escapism)	(Loureiro, 2014; Oh et al., 2007)
Memory	(Loureiro, 2014; Oh et al., 2007)
Pleasantness of the experience	(Kaltcheva & Weitz, 2006)
Telepresence	(Choi et al. 2016)
Student engagement	(Criado & Such, 2011; Isiaq & Jamil, 2017)
Mindfulness (domains: novelty seeking, novelty producing, engagement, flexibility)	(Langer, 2004; Loureiro & Fialho, 2017)

space (installation of the sensors and safety zone delimitation). After installation of the system software, the VR app from Oculus and setting up an Oculus account, the pc only needed an Internet connection for software updates. The chosen video was the "GoPro VR: Swimming with Wild Dolphins in the Ocean", with a duration of 2:11 min and publicly available on YouTube. This video was selected to provide the participants with a new learning situation in order to all of them being in the same path. All the participants (n = 124) in this study started by visualizing the VR video, through the appropriate equipment, and finished their experience by answering a questionnaire to collect their opinions. From the group of participants 58.1% were female and they were well-distributed among a first-degree course, master course and PhD/DBA course.

The questionnaire was first prepared in English due to the fact that the measures of the constructs are in English and then translated to Portuguese and back-translated to ensure that both had the same content and information (Sekaran, 1983). A pilot sample of 10 students was contacted to ensure that the content, design, and structure of the questionnaire were clear and to allow for any final adjustments. Measures of the constructs are adapted from past studies (see Table 1). The questionnaire also contains socio-demographic variables.

The literature contains several scales to measure Mindfulness. For instance, the Kentucky Inventory of Mindfulness Skills, the Mindful Attention Awareness Scale, the Five Factor Mindfulness Questionnaire, or the Langer Mindfulness Scale (LMS). However, LMS emerges as the most suitable because (i) the current study measures individuals' general cognitive state (university student cognitive state) and not the collective cognitive state within an organization; (ii) the scale does not consider a particular context and therefore can be used in different situations, and (iii) there is good test–retest reliability, factor validity, and construct validity demonstrated in other studies and particularly in the scale validation carried out by Langer and others over the years.

4 Findings

A PLS model should be analysed in two stages. First, the measurement model by evaluating the reliability of the individual measures, convergent validity, and discriminant validity of the constructs. Second, the structural model is evaluated. The measurement model does not pose any problematic situation, where item loading, reliability and convergent validity are within the criteria stablished. Regarding discriminant validity, this is examined through two criteria: Fornell-Larcker and Heterotrait-Monotrait ratio. For the first, the square root of AVE (Average Variance Extracted) was greater than the correlation between the construct and other constructs in the model (Fornell & Larcker, 1981). Considering the Heterotrait-Monotrait ratio of correlations, all results took values below 0.90 and so we can claim that the discriminant validity of the constructs has been established.

In the current study a non-parametric approach, called Bootstrap (5000 re-sampling), is used to estimate the precision of the PLS estimates and support the hypotheses (Hair et al., 2017). All path coefficients are found to be significant at the 0.001 level, except hypothesis H6 (see Table 2).

Concerning the mediating effects of pleasantness, memory and both, we examine the direct and indirect effects and interval of confidence. Therefore, memory is a full mediator between pleasantness and student engagement and a partial moderator between telepresence and student engagement (see Table 3).

Finally, the multigroup-analysis reveals that overall, there is a tendency for the path pleasantness → memory ($\beta = 0.275, p < 0.10$) be higher for low mindful students than for high mindful students (see Table 4). Thus, H8 was not supported.

Table 2 Structural results

	Path coefficient	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P value	
VR experience → telepresence	0.687***	0.046	15.075	0.000	H1: supported
Telepresence → S. Engagement	0.269***	0.100	2.676	0.008	H2: supported
Telepresence → pleasantness	0.420***	0.097	4.323	0.000	H3: supported
Telepresence → memory	0.509***	0.103	4.925	0.000	H4: supported
Pleasantness → memory	0.320***	0.101	3.173	0.002	H5: supported
Pleasantness → S. Engagement	-0.033 ns	0.080	0.421	0.674	H6: not supported
Memory → S. Engagement	0.371***	0.101	3.686	0.000	H7: supported

Note: ***$p < 0.001$; *ns* not significant

Table 3 Mediation effects

Relationship	Indirect effect	T statistics (|O/STDEV|)	P values	Bias corrected bootstrap 95% confidence level		Direct effect	
	Path Coefficient			Lower	Upper	Path Coefficient	
Telepresence → pleasantness → memory	0.135	1.862	0.063	0.042	0.280	0.509***	No mediation
Pleasantness → memory → S. Engagement	0.119	2.650	0.008	0.041	0.208	−0.033 ns	**Full mediation**
Telepresence → pleasantness → memory → S. Engagement	0.050	1.776	0.076	0.013	0.116	0.269***	No mediation
Telepresence → memory → S. Engagement	0.189	2.791	0.005	0.071	0.361	0.269***	**Partial mediation**
Telepresence → pleasantness → S. Engagement	-0.014	0.377	0.707	-0.073	0.073	0.269***	No mediation

Table 4 Multigroup analysis: mindfulness with parametric test

	Path coefficients original (Mindfulm (1.0 low)	Path coefficients original (Mindfulm (2.0 high)	t-values (Mindfulm (1.0 low)	t-values (Mindfulm (2.0 high)	p-values (Mindfulm (1.0 low)	p-values (Mindfulm (2.0 high)	Path coefficients-diff (Mindfulm (1.0 low) Mindfulm (2.0 high)	*p*-value (Mindfulm (1.0 low) versus Mindfulm (2.0 high)
Experience VR → telepresence	0.664	0.688	8.338	11.953	0.000	0.000	0.024	0.587
Memory → S. Engagement	0.347	0.353	2.134	2.908	0.033	0.004	0.006	0.505
Pleasantness → memory	0.425	0.150	4.078	0.992	0.000	0.321	**0.275**	**0.065**
Pleasantness → S. Engagement	0.014	−0.040	0.106	0.422	0.916	0.673	0.055	0.374
Telepresence → memory	0.411	0.580	3.264	4.256	0.001	0.000	0.170	0.827
Telepresence → pleasantness	0.457	0.309	5.371	1.966	0.000	0.050	0.148	0.197
Telepresence → S. Engagement	0.271	0.241	1.882	1.910	0.060	0.057	0.031	0.436

5 Discussion and Conclusions

In the current study educational and escapism are the most significant facets in shaping the overall VR experience. This is a valuable result because we start to point out the importance of using VR equipment to enhance the learning process, leading university students to be immersed in a different but enriching experience. VR is known to be very immersive, where participants are invited to be in a different context from their daily lives. Telepresence can be directly associated with student engagement, meaning that the strong sensation of being present positively contributes to engaging students in the learning process through VR. Indeed, VR can even encourage a desire to search for more information about a certain topic through other sources of information. This aspect highlights the importance of engaging participants in a certain cause, as in past research (e.g., Bilro et al., 2019). Although pleasantness of the experience—regarded as the positive feeling and emotions during the experience—is important in the process of creating and maintaining the memory in students' minds, this study shows that memory is a truly mediator between telepresence and student engagement. VR acts as an extrinsic motivation to be engaged (Ryan & Deci, 2000).

All hypotheses were supported except H6, linking pleasantness of the experience with student engagement. Hence, this study shows the valuable influence of creating favourable memories and this seems to increase the willingness to become engaged more efficiently rather than just having positive emotions or being satisfied. Therefore, memories play an important role in the process of engaging students. Mindful students tend to get more memories when they feel pleasure in the learning process than less mindful ones. As expressed in past research, memories are activated and stored through emotions (Itani et al., 2019; tom Dieck et al., 2018; Loureiro, 2014), yet the sensation of being in the VR environment also contributes to creating memories and both telepresence and memory are strong drivers of student engagements.

The study adds to theory by presenting a model that extends the S-O-R framework proposing drivers of student engagement. VR experiences act as a motivational factor to enhance telepresence and this, in turn, influences student engagement, through creating memories. VR experiences are considered effective for college students in acquiring new skills because contribute to creating favourable memories in students' mind about the topic they visualize and hear through VR equipment.

Regarding the higher education institutions (HEI) and faculty members, it seems clear that most of their time is dedicated to students' learning and academic success, through challenging and engaging activities. This is not always an easy task, not because they do not know how to do so, but, mostly because they do not know how to handle some of the existing tools that can help them achieve their teaching goals. We also know that students in HEIs are open for using new technology-based tools and to explore new ways of interaction and learning through these tools. Thus, HEIs should explore new teaching methods, attempting to fill the gap between more traditional teaching methods and technology-based tools and methods.

Faculty members should be aware that students show greater motivation and desire to explore new sources of information and working on their own learning experience. VR can positively influence students' interest, even among those who are not creative or willing to look for new ways of doing things. VR promotes a better learning outcome among students.

The sample of participants is a convenience sample usually employed in experiment studies. The target population was contacted, and the sample represents college students who are in the process of learning in management and marketing courses. Future studies should use more diverse college studies in different cultural contexts to consolidate the findings. Yet, the sample size (n = 136) is appropriated to an experiment. Experiment studies conducted in laboratory usually employ smaller sample size (some employ only 20 participants), as we can see, for instance in Mobascher et al. (2009) or Posada-Quintero et al. (2016). Our sample size is also appropriated to the PLS technique employed. Indeed, Hair et al. (2011) suggest a sample size at a minimum of ten times the bigger set of arrows heading towards any construct, what in this case the sample should be minimum 30 (10 × 3 arrows). Even when considering the power analysis (Cohen, 1988; Hair et al., 2017), the recommend sample size is 136, by utilizing power analysis for a statistical power of 80% (and also 5% level of significance with minimum R^2 equal to 0.10 most conservative case), and maximum number of arrows pointing at a latent variable being equal to 3. However, a larger sample size could be important in the future to consolidate the findings, introduce other interesting variables that enrich the model and create more complexity and even to compare among different cultures.

The VR film should be created and prepared with different material allowing to be adapted to different educational courses. It is important to create the films in VR taken in consideration the pedagogic material of a certain module of the course. In the creative process to make a VR film it will also be possible to introduce some gamification effects to enhance the positive emotions and be able to effectively engage less mindful college students. We also suggest considering AVATARs that could interact with students during the VR experience. The AVATAR may contribute to develop a sense of connection, eventually increasing the positive emotions and the engagement process.

Another suggestion lies in the use of other senses than sight and hearing to increase the sensation of vividness, presence and ultimately the immersion. This will be particularly important to college students less focused on the topic of the courses. Other constructs may be recommended to be incorporated in the model. For instance, sense of power meaning a perception of control over a certain situation (Madzharov et al., 2015). This perception may alter the sensation of telepresence in using VR experience because it is expected that college students with high sense of power will be more critic of everything that then can receive from the VR experience than students with lower sense of power. Another example is the construct of "cool". Can the use of VR experience be regarded as a "cool" tool to learn? Or how a less "cool" leaning material become cool through the use of VR equipment or using the combination of VR and Augmented Reality (Warren et al., 2019)?

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A Virtual Reality Framework for Upskilling in Computer Programming in the Business Context

Ernest Edifor, Alasdair Swenson, and Opeoluwa Aiyenitaju

Abstract More and more, some business professionals need to engage with some sort of computer programming in their roles. Learning programming requires various skills that most people find difficult to learn. Virtual Reality (VR) has gained high recognition as a virtual training technology due to a myriad of benefits. This study proposes a method for teaching and learning programming in a business context. It uses VR to simulate scenarios in the learners' working environment to introduce and reinforce programming concepts. A case study is presented and some discussions are made. The proposed method is validated using the Dooyeweerd conceptual framework.

Keywords Virtual reality · Computer programming · Teaching and learning · Business environment

1 Introduction

Computer programming is no longer a skill delegated specifically to computer programmers. Data analysts and professionals at various levels in the business community are sometimes required to know basic programming constructs to enable them to perform their duties. With the trend set to increase, there is a need for professionals within the business environment to upskill in programming.

It is a known fact that computer programming is a troublesome subject for many learners. How can professionals upskill in programming intuitively to enrich their learning experience while they attain high levels of retention and engagement? This is the question this research hopes to address. The authors propose a novel framework using Virtual Reality (VR) and discuss how the framework could be validated using the Dooyeweerd framework. The proposed method introduces programming concepts to the learners using familiar scenarios in their working environments.

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Firstly, in this chapter, pedagogies for computer programming, VR as a teaching tool, and validation theories for technology acceptance are reviewed using extant literature. Secondly, the proposed framework is presented with a detailed discussion of all its components. Thirdly, a case study is presented to demonstrate how the proposed method could be practically implemented and validated; discussions are made of the results. Finally, a discussion of the potential impact of the study and future directions are identified and discussed.

2 Literature Review

2.1 Programming in the Business Context

Recently, it was estimated that the Digital Skills Gap (DSG) was costing the UK £63 billion a year (House of Commons Science and Technology Committee, 2016) and 35% of jobs within the UK will be automated over the next two decades (House of Lords Digital Skills Committee, 2015); this would affect companies of any size (ECORYS UK, 2016). DSG has necessitated the initiation of various projects aimed at reskilling and/or upskilling professionals with programming skills (Chetty, Aneja, Mishra, Gcora, & Josie, 2018). A key emerging skill necessary for the bridging of DSG in both developed and developing countries is "technology design and computer programming" (World Economic Forum, 2018). Some professionals within the business community will be required to learn computer programming if they are to excel in the future (Nania, Bonella, Restuccia, & Taska, 2019).

At a basic level, some professionals are required to use simple programming constructs and/or features such as *If…Then*, *For…Next* or *Sub…End Sub* etc. in Microsoft Excel VBA. At a higher level, professionals involved in creating reports and dashboards could be required to learn some programming constructs in Microsoft Power BI (using DAX) or Tableau software (using features similar to Microsoft Excel) or python programming.

2.2 Programming Pedagogies

It is widely known that programming concepts are difficult to grasp (Isong, 2014); they are referred to as threshold concept (Sanders & Mccartney, n.d.). A threshold concept (Meyer & Land, 2003) is a conceptual "gateway" or "portal" into a subject without which one cannot gain full mastery of the subject. Many programming concepts could pass as being threshold concepts (Kallia & Sentance, 2017). What makes programming difficult to learn for new learners are the number of skills the learners will have to acquire simultaneously. Novices will have to learn the syntax (formal rigid structure of the code), semantics (the logical meaning of the code), theoretical concepts, problem-solving and analytical skills (Malik & Coldwell-Neilson, 2017). The ability to learn and apply all these concepts and skills in parallel is not something every learner possesses; this leads to a relatively high attrition rate (Miliszewska & Tan, 2007) in computer programming courses.

Various pedagogies have been proposed to enhance the retention rate of students in programming courses by enhancing the learning experience of the students. The traditional lecture-and-lab delivery method is not always appropriate for teaching programming (Isong, 2014; Wulf, 2005). This has led to the development of other techniques such as pair programming (Brereton, Turner, & Kaur, 2009; Salleh, Mendes, & Grundy, 2011), robot-based delivery (Major, Kyriacou, & Brereton, 2012), constructive approach (Wulf, 2005), and an agile approach ((Isong, 2014). Most of these techniques address one or more of the challenges associated with learning computer programming. However, none of them specifically address how business professionals can easily learn to program using familiar concepts in their natural environment. A critical review of these techniques is beyond the scope of this paper.

2.3 Teaching with Virtual Reality

Virtual Reality (VR) is a technology that places users within a digital 3-Dimensional (3D) environment that may be fictional or a replication of the physical world. When used in an education or training context, VR offers an experiential learning experience, granting learners hands-on interactive learning albeit with virtual content (Checa & Bustillo, 2020). In certain use cases, retention and engagement increase where a learner actively engages with a task; similar benefits have been realised with learners in VR environments (Allcoat & von Mühlenen, 2018).

VR presents a myriad of benefits to organizations who embrace the technology and invest in its software, hardware and other associated platforms (Incao, 2018). Immersive experiences are becoming increasingly accessible via the emerging immersive web (W3CI Working Group, 2019) platform. VR will continue to replace and/or complement existing training with potential returns from increased knowledge recall (Krokos, Plaisant, & Varshney, 2019).

VR has gained popularity in sectors such as tourism, medicine, gaming and training of personnel in high-consequence fields (such as medicine, military etc.) but it has seen relatively limited application in the general education domain (George-Williams et al., 2019; McGovern, Moreira, & Luna-Nevarez, 2019). Some researchers have explored the use of VR in business (Lee, Sergueeva, Catangui, & Kandaurova, 2017; McGovern et al., 2019), chemistry (Bennie et al., 2019; George-Williams et al., 2019), languages (Dobrova, Trubitsin, Labzina, Ageenko, & Gorbunova, 2017), crime scene investigation (Mayne & Green, 2020) and computer science (Dengel, 2019; Kong & Kruke, 2018) education. Even though VR is slowly gaining usage in these educational fields, one field that is rarely looked at because it does not fall in the traditional educational domain is the training/upskilling of business professionals. A pedagogical framework to help business professionals to upskill in computer programming using concepts in their work environment is extremely scarce.

2.4 Validation of Technological Systems

There are various Information Systems acceptance models with their strengths and limitations. To highlight some of these, the Activity Theory (AT) (Lantolf, 2006; Nardi, 1996) reveals how language and tools mediate human activity but it is not sufficiently operationalised and it is limited in revealing issues on fun or beliefs. The Technology Acceptance Model (TAM) (Legris, Ingham, & Collerette, 2003) shows how perceived usefulness affects the acceptance of technology, but it sometimes takes attention away from what makes a system useful. Self-efficacy beliefs vary widely among individuals, and thus difficult to assess. High self-efficacy can sometimes lead to overconfidence, resulting in an individual applying less effort to a task (Mueller, Wood, Willoughby, Ross, & Specht, 2008; Redmond, 2016).

Dooyeweerd (1984) produced a comparatively holistic suite of fifteen aspects, that are meaningful in everyday experience. Aspects are introduced as “a way that appeals to our intuition, only later gradually exposing their nature” (Basden, 2008). Each aspect is irreducible to others, yet depends intrinsically on one another (Basden, 2008). A detailed review of these aspects is beyond the scope of this paper, however, some of them will be described and used in later sections.

3 Method

3.1 Framework

The programming language under consideration is python. The authors propose a 4-dimensional intervention to address the research question. As depicted in Fig. 1, the dimensions are pedagogical principle (PP), application domain (AD), competency level (CL) and validation indicator (VI). The PP adopted is the constructive alignment (John Biggs & Tang, 2007), which prescribes that a teaching model must have a direct mapping between intended learning outcomes (ILO), teaching and learning activities (TLA) and assessment tasks (AT). The AD for PP has a range of ***concepts*** (for ILOs) to describe what the learner needs to learn, ***techniques*** (for TLAs) to facilitate the teaching and learning activities and ***metrics*** (for ATs) to measure what the learner has learned.

The AD for ILO includes syntax, semantics and concept. The AD for TLA includes real-world scenarios, a virtual python programming environment (PyDemo) and a

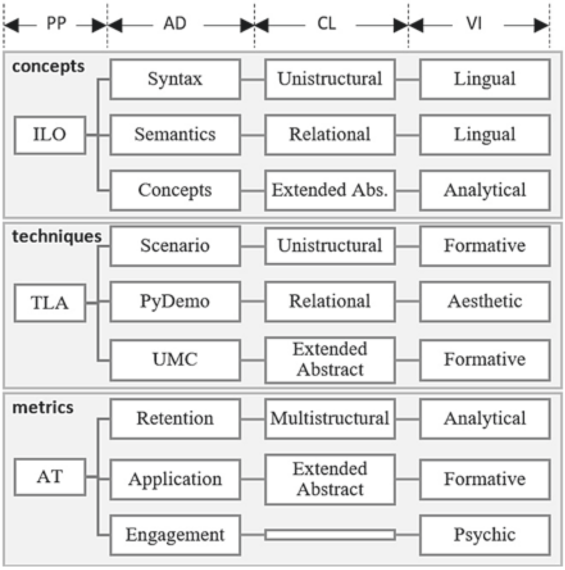

Fig. 1 Proposed Abstract Pedagogical Framework

learning technique (UMC, which, stands for use-modify-create (Lee et al., 2011)). The UMC will be accomplished through a simulation of the operation of a python editor in VR. The AD for AT specifies how various metrics (retention, application and engagement) would be measured.

In the CL, each element in the AD is mapped unto the competency levels in the SOLO taxonomy (Biggs & Collis, 1982): unistructural (identify), multistructural (describe), relational (apply) and Extended Abstract (create). ***Engagement*** is the degree of interest a learner shows in the learning environment hence it requires no mapping to a CL category. The TLA domain will be in the VR environment but the AT domain will be done in IDLE; IDLE is an integrated development environment for python.

Each of the descriptors in the CL has a corresponding VI. Each descriptor in the VI is an aspectual element in Dooyeweerd's philosophy. The VI descriptors show how each of the CL descriptors would be validated.

3.2 Implementation

In this section, the authors describe how a simple programming concept in python—variables—would be taught using the proposed technique to demonstrate its applicability. Table 1 shows a mapping between ILO, TLA and AD.

As indicated in Table 1, the intended learning outcomes are: (1) identify data types and (2) create valid variables and assign them appropriate values. The first ILO sits at the unistructural level of the SOLO taxonomy and the second is at both the

Table 1 A demonstration of the proposed pedagogical framework

ILO ILO1: Identify data types. ILO1 is set in **syntax** ILO2: Create valid variables and assign them appropriate values. ILO2 is set in **syntax** and **semantics**	
AD	**Syntax**: *variable = data* **Semantics**: use meaningful variable names **Concepts**: variables contain data and data belongs to certain types
CL	**Syntax**: identify data types and variables **Semantics**: establish the relationship between variables and values **Concepts**: assign values to valid variables in a meaningful way
VI	**Syntax:** *Lingual*—code must follow a specific symbolic pattern **Semantics**: *Lingual*—certain rules must be followed for meaning to be achieved **Concepts**: *Analytical*—the relationship between variables, data and data types
TLA ILO1: will be met in **Scenario** ILO2: will be met in **PyDemo** using **UMC**	
AD	**Scenario**: present a real-world scenario **PyDemo**: demonstrate how the real-world scenario is automated in python **UMC**: use and modify example, automate a new scenario
CL	**Scenario**: identify data types and variables **PyDemo**: establish the relationship between variables and values **UMC**: create variables and assign values to them meaningfully
VI	**VR**: *Formative*—validating the functionality and compliance of the technology **Scenario**: *Aesthetic*—use familiar scenarios participants would recognise and enjoy **UMC**: *Formative*—participant demonstrates a good understanding of the process for achieving the task

(continued)

relational and the extended abstract levels. All these elements will be validated using the lingual and analytical aspects of Dooyeweerd's framework; brief descriptions of these aspects have been provided in the table.

In the TLA phase, the learner is presented with a 3D model of a real-world scenario they would be familiar with in their business context, for example, a letterbox—Fig. 2. The scenario will introduce them to aspects of the natural world that would

Table 1 (continued)

ILO ILO1: Identify data types. ILO1 is set in **syntax** ILO2: Create valid variables and assign them appropriate values. ILO2 is set in **syntax** and **semantics**	
AT ILO1: will be assessed in **retention** ILO2: will be assessed in **retention** and **application**	
AD	**Retention**: identify the syntax for creating a variable **Application**: create a variable and meaningfully assign an appropriate value to it **Engagement**: active engagement in completing all tasks and activities
CL	**Retention**: define a valid variable **Application**: assign a value to a variable meaningfully **Engagement**: N/A
VI	**Retention**: *Analytical*—identify distinct and valid variable names **Application**: *Formative*—ability to create meaningful variables with values **Engagement**: *Psychic*—accomplish all tasks as intended

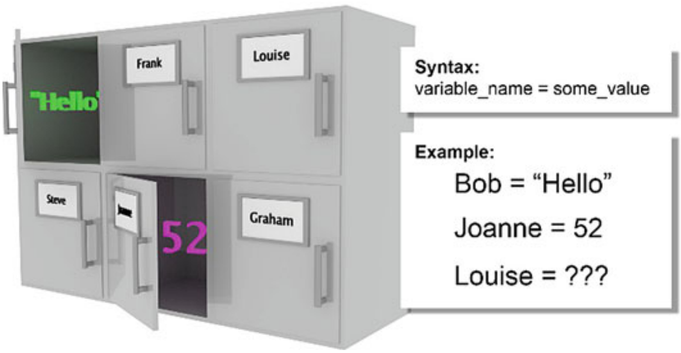

Fig. 2 Real-world scenario

be automated in a programming language. A transition from the real-world scenario to the programming construct is initialised using the VR environment. The learner will then learn how the real-world scenario can be represented in a programming environment. In Fig. 2 Joanne's letterbox contains the value 52, however in python, using the syntax *variable_name* = *some_value,* this could be written as *Joanne* = *52*.

After the concept has been introduced, the learner will be given a series of tasks to perform; these will reinforce the programming concept. They will then have the opportunity to modify these tasks to determine the results of their changes. Finally, the tasks will require the learner to create new variables and assign them values. The final tasks will present opportunities for formative feedback to further reinforce the concept the learner has learned. All the TLA activities will be accomplished in a VR environment.

At a later date, during the AT phase, the learner will be assessed for their retention, application and engagement by completing a series of incrementally challenging tasks. For ***retention***, a scenario-based assessment will be set in IDLE to test the learner's ability to identify valid variables data types. The ***application*** tasks will assess the learner's ability to create meaningful variables and assign appropriate values. The ***engagement*** activities will assess the learners level of completion and engagement. All the AT tasks will be accomplished in IDLE.

3.3 Validation

In the proposed VR-based framework, the authors employ the use of a validation approach that emphasises general principles applicable to everyday experience rather than specific theories. Understanding human behaviour from a multi-aspectual functioning perspective is richer than a uni-aspectual functioning perspective which is mostly offered by psychology, linguistics or economics. Humans relate to computers in different ways. A specific aspect is how people engage with meaningful information a computer processes or presents. To validate the acceptance of using VR to teach computer programming, learners would need to be familiar with and/or how information is presented to them. They have to learn things like syntax, semantics, problem-solving, how to input data, the format of the data etc.

4 Case Study

To demonstrate the application of the scenario in the implementation section, the authors use the 2D images in Fig. 3 to show how a VR environment could be created to practically implement their proposed solution.

Figure 3A is a welcome screen with a menu for the learner to choose a topic they wish to study. **Figure 3B** is a splash screen giving pertinent information to easy the learner into the session. **Figure 3C** uses a typical business environment to introduce the programming concept to the learner. The learner gets to interact with the virtual environment with functions and features similar to that of the real-world; the learner gets to 'use' the concept. In **Fig. 3D**, the learner is taught how to translate the business environment concept into python. In addition to the concept, syntax and semantic are introduced here. **Figure 3E** allows the learner to interact with a business

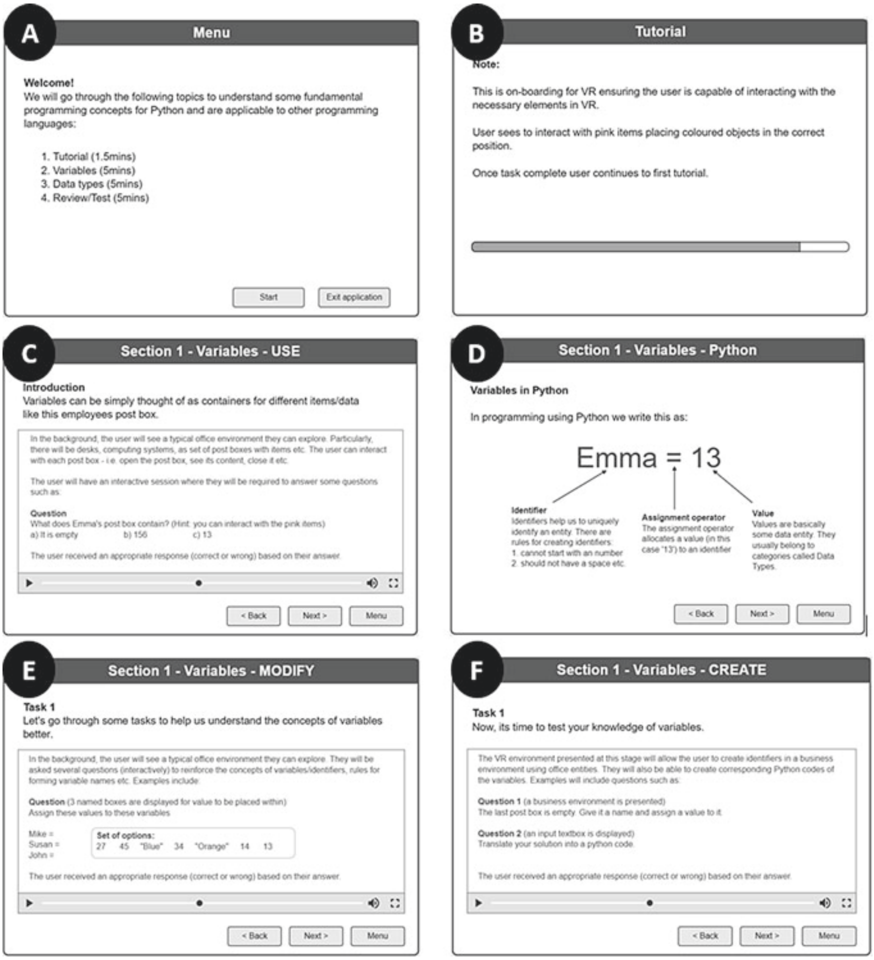

Fig. 3 Demonstration of implementation

environment version and python version of case studies that they can ‘modify’ to see the effects of the modification; they do these through a set of tasks. In the business environment case, they interact with a typical office environment in VR but in the python environment case, they interact with a set of python scripts on the screen. In **Fig. 3F**, the learner ‘creates’ various scenarios using the business environment and python environment. At this stage, the learner demonstrates their understanding of the concepts. For the ILO dimension, the syntax, semantics and concepts for the AD, CL and VI will be captured by the screens in **Fig. 3C**. The TLA for AD, CL and VI will use or capture scenario, PyDemo and UMC by the screens in **Fig. 3C-F**. Retention, application and engagement of the TA dimension are captured in **Fig. 3E, F**.

5 Discussion

As discussed earlier in Sect. 2.2, there are many pedagogies for teaching computer programming. Although the proposed technique is a conceptual framework, as demonstrated in the case study, it has benefits which some traditional and contemporary pedagogies do not have. Firstly, it provides an engaging and visually stimulating environment to enrich the learners' experience. Secondly, it uses familiar concepts in a typical business environment to teach unfamiliar programming concepts in a programming language. Finally, it employs a rigorous framework to validate the usability of the proposed solution.

In future, the researchers hope to perform empirical research to determine the engagement, application and retention benefits learners will gain from using the proposed system compared to the use of other traditional computer programming pedagogies. Also, the model will be improved to include problem-solving skills.

6 Conclusion

Increasingly, computer programming is becoming a skill some business professionals need. With the trend set to increase, professionals within the business community would have to learn programming, which is deemed a difficult concept for many learners. The authors have proposed a conceptual framework based on virtual reality, constructive alignment, solo taxonomy and Dooyeweerd's philosophical framework. The proposed solution is designed to help novice programmers learn programming easily through the use of concepts, processes and scenarios in their familiar environments. The next step of this research is to implement the framework by performing experiments and reporting and discussing the results.

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Immersive Technology Design and Development

Recognition of Facial Expressions in VR an Experiment of Still Photos Versus Three Dimensional Computer Graphic Images

Joey Relouw, Marnix S. van Gisbergen, and Carlos Pereira Santos

Abstract Modern techniques, such as photogrammetry, allows for capturing humans and convert them into realistic looking three-dimensional digital humans. Scanning human faces through photogrammetry and applying them into realistic virtual environments becomes more affordable and easy to use. However, it is unclear whether people differ in recognizing human expressions from 3D photogrammetry faces compared to those captured through traditional media such as photographs. In this study, we compared recognition of ten facial expressions (irritation, hot anger, sadness, despair, disgust, contempt, happiness, elated joy, panic fear, and anxiety) with two intensity levels taken from computer graphic (CG) scanned faces and photographs of two actors. The results, taken from a hundred participants aged between 18–55 years old, showed no differences in facial expression recognition between traditional photographs and computer graphic images. In addition, in line with previous research, the overall recognition of expressions was relatively low (around 50%). These results suggest that CG scanned faces, without any optimization, can already be used within VR environments without risking a loss of expression recognition. However, the results also advocate developers to invest time and money in optimizing the realism in photogrammetry scanned faces to increase the chance of recognizing the right facial expressions when communicating through human faces in virtual reality.

Keywords Photogrammetry · Photographs · Expressions · Recognition · Computer graphics

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1 Introduction

Over the last decade, the level of realism of three-dimensional (3D), Computer Graphics (CG) has increased (Community BUFF, 2018). By applying modern techniques such as machine learning, procedural generation, artificial intelligence and photogrammetry, new possibilities are arising for CG developers in Virtual Reality. Photogrammetry techniques obtain reliable information about physical objects and the environment through the process of recording, measuring and interpreting photographic images (Aber et al., 2010). It refers to the process of creating 3D models from multiple two-dimensional (2D) images. Specialized software uses multiple 2D images that through means of triangulation creates 3D dimensions of an object or person. Although the results are very good, they often still contain errors, such as gaps of missing 2D information or distortion in complicated shapes such as hair or transparent materials. This is where 3D artists intervene and improve the result of the automated photogrammetry process to make it usable in a media product. However, it remains unclear how much optimization is needed when creating digital humans.

Photogrammetry is being used to capture human faces for multiple specialized fields. Medical applications, computer animation, video surveillance, teleconferencing and virtual realities are some examples (D'Apuzzo, 2002; Ey-Chmielewska et al., 2015; Linder, 2014). Another example is the creation of Artificial Intelligence (AI) news anchors, like Xinhua, Qiu Hao, or Zhang Zhow (Loeffler, 2019). The use of AIs allows for one anchor to present two different stories at the same time to different TVs or displays. The question of whether CG and AI can replace humans is becoming increasingly important (Elezaj, 2018). The photogrammetry studio at Breda University of Applied Sciences used in this experiment (see Fig. 1) is among others developed for the project VIBE (Virtual Humans in the Brabant Economy). With a consortium of 13 partners, VIBE aims to develop virtual humans for training purposes in the healthcare industry. The project monitors human communication in healthcare settings, builds virtual humans based on these data, and then tests the virtual humans in similar settings. The avatars communicate with their human users via speech, facial expressions, and nonverbal behaviors in virtual, mixed, and augmented reality environments. Such interactive avatars can be deployed in several domains, particularly those domains for which interaction is critical, such as healthcare. These avatars can support the training of caregivers, or provide information to patients (Project VIBE, 2017).

Although each field has a different use case, most often, they all aim for a high level of realism (D'Apuzzo, 1998; Luhmann et al., 2013). Whether digitizing humans is performed for purposes of entertainment or for serious virtual reality applications, it remains, however, unclear how much optimization or realism is needed for the audience to be able to read and recognize the intended meanings behind facial expressions. No benchmark of expression recognition of digital faces exists to make substantiated choices on the level of optimization needed when digitally capturing human faces. Previous research indicated that high realism is not always needed to communicate effectively with Virtual Reality users (van Gisbergen et al., 2020). Studies that make comparison between the recognition of facial expressions in photographs and CG images is missing or have used Avatars that lack the level of realism that is possible to create nowadays. The experiment "Interpreting Human and Avatar Facial Expressions (Noël et al., 2009), has a similar design as the one used in this study. The study also compares human faces versus avatars based on the same seven expressions and makes use of the same FACS method, nevertheless, uses avatars that are not as realistic as used in our experiment (see Fig. 2).

However, although photogrammetry captured human face provides a realistic image; audiences often report that without improvements by artists and developers, it often appears to be lifeless (Statham, 2018). Therefore, developers convert 'raw'

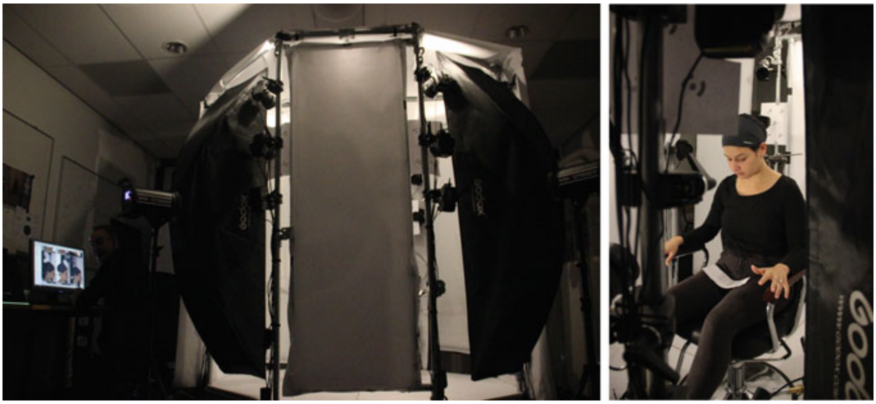

Fig. 1 The photogrammetry rig at Breda University of Applied Sciences used for this experiment

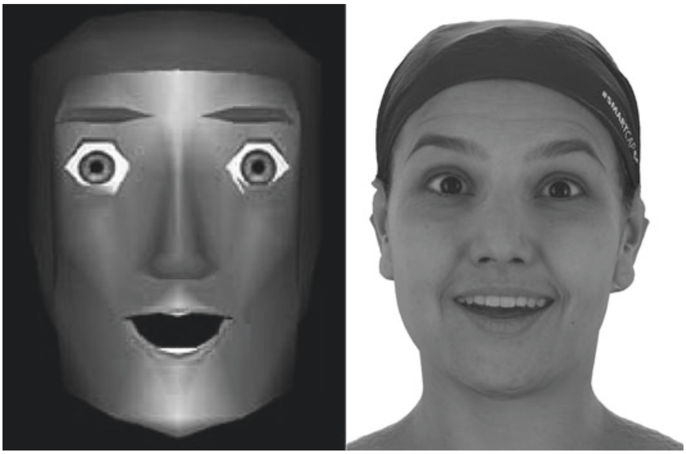

Fig. 2 Example of the "less realistic" avatar used in previous studies (left) and the more realistic one based on photogrammetry scan used for this project (right)

CG models into optimized avatars by adjusting for instance, *shaders* and *topology* and add extra features such as hair, cavities, and animated facial expressions. However, during this phase of altering digitally captured faces, there is a high risk of a negative uncanny valley effect due to human error (Slijkhuis, 2017; Ho & Macdorman, 2010). The uncanny valley idea claims that a too high level of realism of avatars in VR might increase the perceived "*creepiness*" of the avatar (LaValle, 2017; Mori, 1970; Seyama & Nagayama, 2007; van Gisbergen, et al., 2019).

By making use of the newest photogrammetry capturing system, we have set up a new study to provide insights in the number of expressions that are recognizable on realistic CG human faces compared to actual photos of same human faces. In doing so, we will help R&D teams in deciding whether and which human expressions need more optimization, budget and time spend, to at least reach the same level of performance as is created through photographs. The current study provides a basis for a better understanding on how to create a realistic digital representation of a face. Expressions created by developers can be perceived differently by the audience. For example, if a developer aims to create an angry expression within a digital captured CG avatar, the audience may perceive it differently, and read instead of anger expressions like rage, jealousy, or sadness.

This study assists developers in understanding if the intended expressions align with the perceived emotional states, and whether they can reach the same level of correct recognition as in the use of photos. As such, this study also helps to decide whether photographs can be replaced by photogrammetry captured CG images from human faces. Companies often need to make a choice between using photographs or CG faces, and the arguments for each choice are diverse (e.g., photos are easier and less expensive to create, whereas CG images are more expensive but also more adjustable). The study aims to contribute to the decision-making by providing insights into the differences and similarities of facial recognition of human expressions captured through photographs or photogrammetry scanning.

2 Study

In this study, we measured the recognition of facial expressions of digital representations of real human faces. An in-between-two-group design was used, dividing participants in either the photograph human face group or the photogrammetry computer generated human face group (CG group). The participants were invited to participate in the experiment as an online rating study. The design was based on the MERT experiment from Bänziger et al. (2009). Each test started with Informed Consent and an explanation of the experiment. After the consent was given, an example question appeared, allowing the participant to test if the experiment ran on their device. The example questions also made participants familiar with the pace of the displayed photos (time-limit on viewing time) and the possible answers they could provide when rating expressions. Subsequently, the measurements of facial recognition started. The experiment ended with generic questions about recognition difficulty, demographic measurements, actor familiarity, as well as the possibility to leave feedback and comments.

Participants
A total of hundred participants ranged between 18 and 54 year of which 43% was female, and most were from the Netherlands (73%). CG developers and experts were excluded from participation.

Materials
Emotions are mental states associated with thoughts, feelings, behavioural responses and a degree of pleasure or displeasure (Ekman et al., 1994). Emotions are linked with a mental state which often has a physical manifestation revealed through facial expressions. An expression, the position of the muscles beneath the skin of the face, is a form of nonverbal communication to convey the emotional state of the sender (Freitas-Magalhães, 2011). Based on the Plutchik Wheel of Emotions (Cowie et al., 2001), ten facial expressions with two intensity levels were captured from a male and female actor. The ten expressions represented irritation, hot anger, sadness, despair, disgust, contempt, happiness, elated joy, panic fear and anxiety. They were captured for one group based on photographs and for the other group based on a photogrammetry CG scan.

The scans were made in a highly modern capturing studio that enables the capture of high-resolution photographs of the human face and upper torso. A total of 33 individual cameras capture a subject simultaneously from multiple angles, after which a computer converts the photographs into a 3D model (Fig. 3).

The photogrammetry studio captures 40 different individual models or expressions from a single person, which are called poses. These 40 individual poses (single 3D models) can afterwards be connected, creating a single animated *base-model.* This generates realistic fully animated 3D avatars, which can be controlled by 3D rendering software, such as a game engine (Fig. 4).

Fig. 3 A CG face generated through photogrammetry using 33 photos captured from different angles

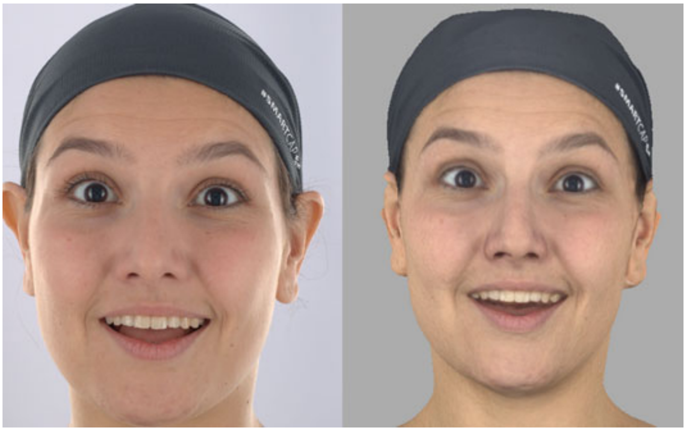

Fig. 4 The difference in visuals shown to the groups. On the left a photograph, on the right the CG model of the same actor

Measures

Expression Recognition Human facial expressions consist of three categories (Liong et al., 2016). The first category concerns the macro expressions, which are visible for 0.5–4 s and are obvious to the eye. The second category is the so-called micro-expressions, which are visible for less than half a second, and mostly happen when trying to conceal the current facial expression. The third category is the subtle expressions, which are associated with the intensity and depth of the underlying macro and micro expressions, and almost invisible to the human eye. To measure expression recognition, the same measurement was used as in the MERT experiment. Each expression was displayed for two seconds after which participants needed to select the expression represented in the face out of ten possibilities that represent the ten main expressions (See Fig. 5). The ten main expressions contain the '*the primary big six expressions*' that humans are able to recognize as from birth, being hot anger, sadness, disgust, panic fear, happiness, and elated joy) as well as four '*secondary expressions*' we learn to identify throughout our lives; irritation, despair, contempt and anxiety (Prinz, 2004). Each expression was displayed four times to a participant; twice per actor, in *two different intensities.* Intensity level 1 expressions are more subtle and as such, expected to be more difficult to recognize. Level 2 expressions are more defined and exaggerated compared to level 1, and as such, expected to be more easily recognized.

During the study, it was noticed that participants mainly had difficulties with distinguishing between the overlapping negative and positive emotions (e.g., "it is hard to distinguish between contempt and irritation" and "…for me there was some overlap between the negative emotions such as disgust and contempt"). As such we decided also to measure combined recognition of related *families of expressions*: Happiness and Elated Joy; Panic and Fear and Anxiety; Despair and Sadness; Irritation and Hot Anger, and Disgust and Contempt.

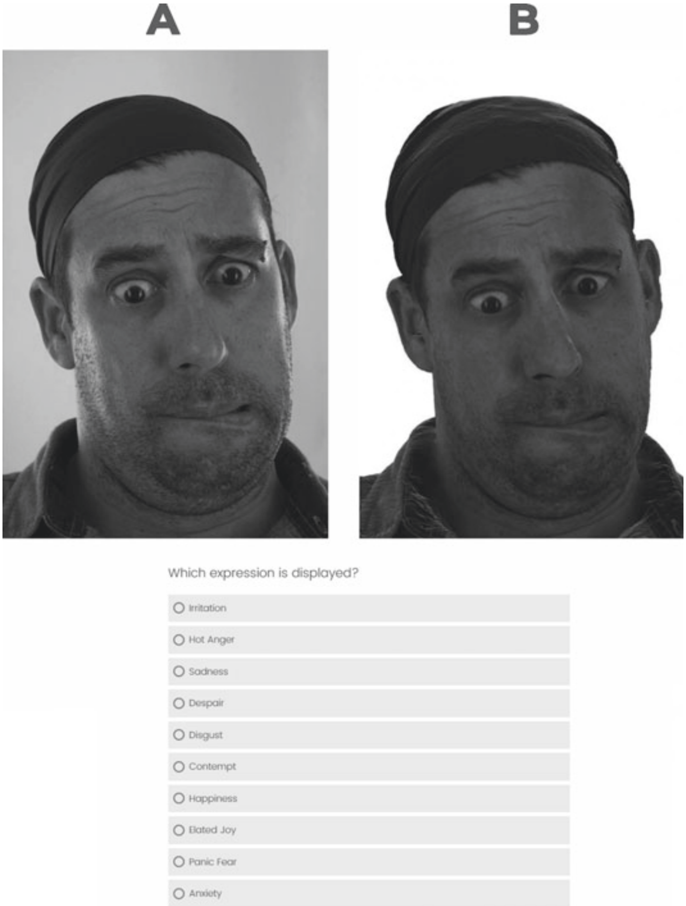

Fig. 5 Example of a an expression recognition question used in the study, however now with both versions of the actor side by side (photographs on the left and CG on the right), while a participant only would see one version

Expression Difficulty In addition, we measured whether participants experienced difficulties in recognizing expressions. Through seven-point Likert scale participants could rate the difficulty of determining the displayed expressions (1 = extremely easy, 7 = extremely difficult). Both groups did not differ in experienced expression difficulty ($X^2(5, N = 100) = 0.124$, $p = 0.910$, two-tailed).

We also measured *estimated expression recognition ability.* On a seven-point Likert scale (1 = not well at all, 7 = extremely well). The groups showed no difference in the estimated ability to read facial expressions ($X^2(4, N = 100) = 0.106$, $p = 0.891$, two-tailed).

CG Familiarity To understand whether participants were familiar with CG generated faces, they were asked how frequently they watch VFX movies and play videogames. No differences were found between the groups in VFX movie frequency ($X^2(4, N = 100) = 3.731$, $p = 0.444$, two-tailed) and frequency in playing computer games ($X^2(4, N = 100) = 2.940$, $p = 0.568$, two-tailed).

Background Variables The groups showed no differences in gender, between ($X^2(1, N = 100)$, $p = 0.545$), age distribution ($F(0.935)$, $p = 0.427$), level of education ($X^2(6, N = 100) = 2.3$, $p = 0.604$, two-tailed).

3 Results

Expression Recognition

No differences were found in the overall correct recognition of facial expressions between the groups $M_{photo} = 41\%$, $M_{CG} = 38\%$, $t = 0.241$; $df = 76$; $p = 0.810$, two-tailed). The combining of families of expressions resulted in higher recognition scores for both groups $M_{photo} = 60\%$, $M_{cg} = 56\%$, $t = 0.691$; $df = 8$; $p = 0.509$, two-tailed). As expected the big six primary expressions were better recognized compared to the secondary expressions within both groups. No differences were found between the groups differentiating between the big six ($t = 1.139$; $df = 10$; $p = 0.281$, two-tailed) and the secondary expressions ($t = -0.8$; $df = 6$; $p = 0.454$, two-tailed) (Tables 1 and 2).

Expression Intensity Recognition

As expected, the higher intensity expression levels were better recognized. This result was visible within the Photograph Group with a difference of 13% of correct recognition ($t = 1.467$; $df = 38$; $p = 0.0151$, two-tailed) as well as in the CG Group with a difference of 15% correct recognition ($t = 1.744$; $df = 38$; $p = 0.089$, two-tailed).

Actor Gender Differences

For both groups expressions with a female actor were better recognized compared to the male actor male actor. This result was present for the overall expression recognition ($M_{female} = 53\%$, $M_{male} = 30\%$, $t = -3.129$; $df = 8$; $p = 0.014$, two-tailed) and the combined families of expressions ($M_{female} = 67\%$, $M_{male} = 49\%$, $t = -3.129$; $df = 8$; $p = 0.014$, two-tailed).

Table 1 Percentage of participants that recognized expressions correctly by visual capture

	Photographs (%)	CG (%)	t	p	n
Overall Expression Recognition	41	38	0.241	0.810	100
Family Expression Recognition	60	56	0.691	0.509	100

Table 2 Percentage of participants that recognized each expressions correctly by visual capture

	Total (%)	Photographs (%)	CG (%)
Hot anger	68	71	66
Disgust	65	70	61
Sadness	59	63	56
Happiness	44	43	46
Irritation	31	31	32
Anxiety	31	31	32
Elated joy	29	30	27
Panic fear	28	32	25
Contempt	27	25	29
Despair	21	19	24

4 Conclusion

This study reveals that as expected, the ability to recognize expressions of human faces portrayed through any form of media is relatively low. The average recognition of 40–60% of the expressions is congruent with findings from previous studies. Matsumoto and Hwang (2011) stated that the average accuracy of correct recognition rate was 48% in their study. When excluding the two easiest expressions to recognize, joy and surprise, the accuracy rate dropped further to 35% (Matsumoto & Hwang, 2011). Others have similar results. In other study, that measured the awareness of facial micro- and macro expressions, the average awareness rate was approximately 58% (Qu et al., 2017).

Moreover, the results seem to suggest that there are no differences in our ability to extract expressions from human faces through traditional photographs or innovative 3D photogrammetry scanned human faces without optimizing processes. This seems in line with previous that indicated that VR faces are as valid as standardized Photographed faces for accurately recreating humanlike facial expressions of emotions (e.g., Dyck et al., 2008; Fabri, Moore, & Hobbs, 2004; Gutiérrez-Maldonado et al., 2014). These results suggest that the Uncanny valley effect partly is solved utilizing these new technologies when using digital stills of human faces. This seems to advocate the use of these photogrammetry faces when creating virtual humans in Virtual Reality. As the possible expected drawbacks of being less able to communicate expressions in virtual human faces compared to photographs did not happen, while positive benefits as being able to manipulate the 3D scanned faces in VR remain. Additionally, the use of 3D scanned faces in VR might be further promoted as the faces used in this study did not go through an optimization process. This means that facial expression recognition scores might even further go up when they are enriched with animation and movement and rotation, which is not possible with photographs. A photograph captures only one perspective, while a 3D CG model allows editing and changes potentially decades after the scene was captured. The 3D CG models can also be used in a context that may require dynamic animations, such as in Virtual Reality applications ranging from games to medical applications. This might outweigh the higher costs of creating them compared to photographs. However, the question arises whether an optimization will be achieved as the recognition scores for photographs were relatively low as well. The question remains how much recognition we can achieve with new the help of new technologies, as there might also be a ceiling effect in correct recognition of expressions. Interviews with participants might reveal why people experience difficulties with the correct recognition of an expression and what familiarity of a face or a person can attribute to correct recognition.

In addition to our main finding, there are two relevant findings that may directly contribute to the quality of the development of 3D CG models. First, it seems people have more difficulty in correctly recognizing expressions of male humans. This finding replicate results from another research (e.g., Cahill, 2006; Wingenbach et al., 2018). However, in this study, this might also be because the female actor used in this study has more experience in creating and communicating facial expressions compared to the male actor. In future research we will open dialogues with participants and extend the number of scanned faces. This might help to decide whether Virtual Reality human developers might consider using mainly female actors or allocate more budget to optimization processes when using male actors/avatars. Second, when looking at the individual expressions created by the actors, the results suggest eye contact is very important for the ability to recognize expressions. Therefore, this research suggests that CG faces used in interactive media will be enhanced by the ability of the 3D CG model to maintain eye contact. Further research will focus on using different actors (cultural backgrounds) as well as measuring expression recognition when being able to rotate and move the digital human faces. In addition, we will research whether it also influences the liking of the digital human. Although more research is needed, this study reveals that we currently have the technology to easily digitally capture human facial expressions that have the same effect and potential as photographs without optimization processes that create extra costs and effort. This means that for many organizations, the use of digital humans, whether representing familiar or unfamiliar humans, is becoming more a real and doable option. However, much work needs to be done on representing moving facial expressions. This study provided a first steppingstone that shows the potential of capturing human expressions through photogrammetry capturing. In future studies, we will test the effect of creating digital humans within the health sector as part of a larger project called VIBE (Project VIBE, 2017). In this project, we will focus on developing virtual humans (avatars) to be used for training purposes in the health sector.

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Making 3D Virtual Cities VR Ready: A Performance Study

Werner Gaisbauer, Jonas Prohaska, Ulrich Schweinitzer, and Helmut Hlavacs

Abstract It is important when making 3D virtual cities for virtual reality (VR) that they perform well as a "break in presence" (BIP) might occur when the FPS becomes too low. The key contributions of this research paper are a performance analysis that checks whether two separate virtual cities are "VR ready" on a recommended specification system to qualify for the Oculus Store (i.e., applications must meet a consistent 90 frames per second (FPS)) and several guidelines that are important when rendering large virtual cities for VR. Both virtual cities (Endless City Driver versions) without pedestrians and parked vehicles (but with foliage in the case of the next generation) are VR ready. Reducing the city tile size by half resulted in a much better performance in general.

Keywords Virtual cities · Virtual reality · Performance study · Presence · Procedural content generation · Unity

1 Introduction

For the development and implementation of virtual reality (VR) applications, it is important to balance *performance* and *quality* (Maleki, 2019). For performance, applications must meet a consistent 90 frames per second (FPS) on a recommended specification machine[1] to qualify for the Oculus Store (Oculus Developer Center,

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[1]Oculus Rift and Rift S minimum requirements and system specifications are given in https://support.oculus.com/248749509016567/.

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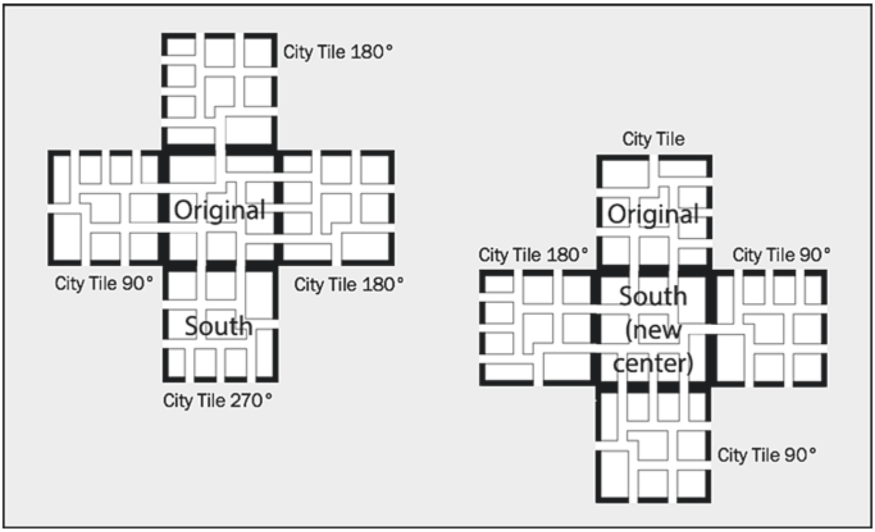

Fig. 1 City tile expansion

n.d.) (we call this application criterium "VR ready" in this paper). For quality, we want the users to experience presence ("the feeling of being there") when in a VR application (Heeter, 1992). VR ready is a crucial requirement for presence as a "break in presence" (BIP) might occur when the FPS suddenly changes or becomes too low (Slater & Steed, 2000). The main research question of this paper is how to create 3D virtual cities with presence and make them VR ready. With that goal in mind, we study the presence enhancing systems of two different existing 3D virtual cities (Endless City Driver original version and next-generation) as described in (Gaisbauer et al., 2020) and try to make them VR ready using a performance study with different city tile sizes. The city generating algorithms work by procedurally generating a realistic 3D endless city from "glueing together" (and rotating in the case of the Endless City Driver original version) a limited number of city tiles (see Fig. 1). The presented research may also be highly relevant for the visualisation of smart cities or tourism in a VR application (Bouloukakis et al., 2019; Gretzel et al., 2016; Lv et al., 2016; Peng et al., 2013) as the guidelines in Sect. 4 could help to make them VR ready.

2 Literature Review

2.1 Procedural Content Generation of Virtual 3D Cities

Prior procedural content generation (PCG) research includes one of the first procedurally generated cityscapes found in the field (Ingram et al., 1996), which is important

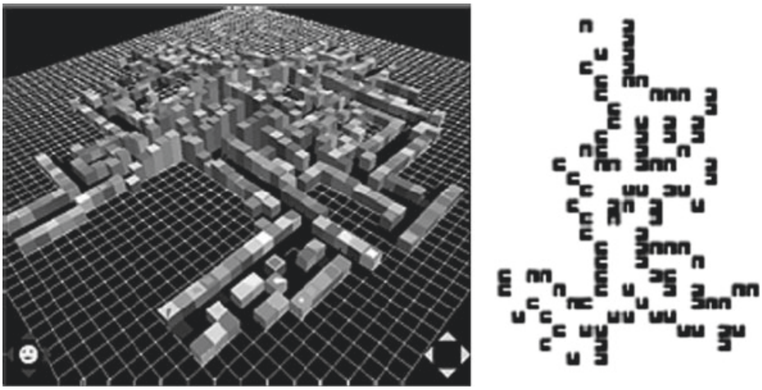

Fig. 2 Procedurally generated cities from (Ingram et al., 1996)

for historical reasons. It describes the design, implementation and experimental evaluation of a city generation system called The Virtual City Builder (VCB). Figure 2 shows virtual cities generated by VCB and visualised in DIVE 3.0 developed at the Swedish Institute of Computer Science (left-hand side) and a labyrinth-like VCB city (right-hand side). Other important previous work on procedural generation in the virtual city sense is a survey on how to create populated cities using procedural generation (Gaisbauer & Hlavacs, 2017) that does not cover the exact procedural approach used here but is relevant due to the urban theme. The construction of a procedural city as a background scenario using Maxim Gumin's internet-famous WaveFunctionCollapse algorithm as discussed in (Oliveira et al., 2018) is an interesting counterpart to our research since it also aims to create endless cities and uses city tiles that are glued together to achieve this. However, the procedurally created buildings are not photorealistic, and the street layout is somewhat more straightforward. Highly relevant research in (Greuter et al., 2003; Hendrikx et al., 2013; Smelik et al., 2014; Watson et al., 2008) mainly discusses how to generate sophisticated virtual cities using procedural generation. However, this research does not detail how endless content can be generated. We think this problem at hand is non-trivial because it is necessary to connect the tiles and the streets seamlessly.

2.2 Other Pedestrian Systems

Other pedestrian systems to be found in the literature are (Boes et al., 2012) and the "crowd patches" approach of (Yersin et al., 2009). The first one aims at the real-time simulation of small crowds of pedestrians (one to two hundred individuals) with visual realism and the second one illustrates the real-time population of potentially infinite cities with realistic and diverse humans interacting with each other and their environment (maximum of 3000 pedestrians). Both are aimed at real-time or

Fig. 3 Pedestrians from (Boes et al., 2012) on the left-hand side and crowd patches from (Yersin et al., 2009) on the right-hand side

almost real-time simulation of pedestrians. However, crowd patches have some limitations, e.g., character motions are precomputed and fixed, which limits extensive interactivity between the pedestrians and the user (Fig. 3).

3 Methods and Approach

3.1 Comparison of Virtual 3D City Environments

3.1.1 Comparison of Presence Systems

Table 1 compares the presence systems for both Endless City Driver versions (Endless City Driver (The Original Version) denoted by ECD TOV and Endless City Driver (The Next Generation) denoted by ECD TNG). All dynamic systems and other city

Table 1 Comparison of systems that are important for presence in virtual cities between two Endless City Driver versions (ECD TOV and ECD TNG)

	ECD TOV	ECD TNG
Subjective personal presence		
Avatar (Jeep vehicle)	+	+
Familiar city layout	+	+
Familiar photorealistic static objects	+	+
City and avatar sounds	+	+
Realistic physics	+	+
Social presence		
Pedestrian system	+	+
Traffic AI system	–	–
Environmental presence		
Randomly parked vehicles	–	+
Traffic light system	+	–
Day and night system	+	+
Weather system	+	+
Street light system	–	+
Window light system	–	+

The + sign indicates that a presence system is present and – indicates that it is absent

features that are important for subjective, social, and environmental presence, as discussed in (Gaisbauer et al., 2020) are listed. In a second step, it is checked if they exist in the different Endless City Driver versions to give the reader an overview of which version uses what kind of presence enhancing systems and also an idea about general graphical world content complexity.

3.1.2 Comparison of Performance

We made a performance study to test how the Endless City Driver performs in action while the test user[2] is driving through the cityscape, comparing the original version (ECD TOV) alongside the next generation (ECD TNG). The main goal for this performance study was to determine which ECD version is VR ready out of the box on a recommended specification machine and to see how much the performance can be improved by reducing the city tile size by half for the ECD TNG.[3] We used an FPS counter for the Unity video game engine to measure the average FPS (Code Stage, n.d.). In our experimental setup, the test user drives through the city for one minute, and subsequentially the average FPS is determined. We tested with

[2]The first author.

[3]For the ECD TOV this was not easily possible as the tiles were handmade, and the tiles do not fit together anymore if cropped.

Table 2 Comparison of performance between two Endless City Driver versions (TOV and TNG) in order to determine which ECD version is VR ready depending on different features

	TOV	TOV	TNG	TNG	TNG	TNG	TNG	TNG
Blocks per city tile	N/A	N/A	6×6	6×6	6×6	3×3	3×3	3×3
City tile size	500^2	500^2	504^2	504^2	504^2	252^2	252^2	252^2
Pedestrians	Y	N	Y	N	N	Y	N	N
Parked vehicles	N	N	N	Y	N	N	Y	N
Foliage	N	N	Y	Y	Y	Y	Y	Y
Average FPS	77	119	38	19	55	62	68	100
VR ready	N	Y	N	N	N	N	N	Y

100 pedestrians that are spawned within the range of 100 m (in both cities) and procedurally generated randomly parked vehicles on the sides of each street for all city blocks (just in the ECD TNG). Our test machine was an Alienware Aurora R5 PC with an Intel(R) Core(TM) i5-6400 processor (up to 3.3 GHz), 8 GB of memory, and an NVIDIA(R) GeForce(R) GTX 1070 graphics card which meets the requirements for a recommended specification machine to qualify for the Oculus Store (Oculus Developer Center, n.d.). Table 2 shows the results of the performance study. The baseline versions of TOV and TNG without pedestrians and parked vehicles (but with foliage in the case of TNG) are both VR ready. Reducing the city tile size by half resulted in a much better performance in general. The rendering of the vehicles takes more frames than the rendering of the pedestrians (although pedestrians have more polygons) because there are 4200 vehicles in the 6×6 city tiles version and 840 vehicles in the 3×3 tiles version as opposed to just 100 pedestrians. Note, that foliage (which is always on in TNG) is also expensive to render.

4 Findings and Discussion

Based on our experience with the performance study, we found the following guidelines to be important when rendering large virtual cities for VR (i.e., “Making 3D Virtual Cities VR Ready”):

- Minimise graphical content (use city tiles as small as possible, but not smaller[4]) and expand the city dynamically during runtime
- Create city tiles offline and not during runtime for faster rendering
- Use procedural generation to create city tiles for extensive city content without the need for handmade tiles (saves time and effort and creates variety if done soundly)
- Use and maximise presence enhancing systems to create the “feeling of being there” (Gaisbauer et al., 2020)

[4]The tiles should be large enough so that the end of the world is not easily visible.

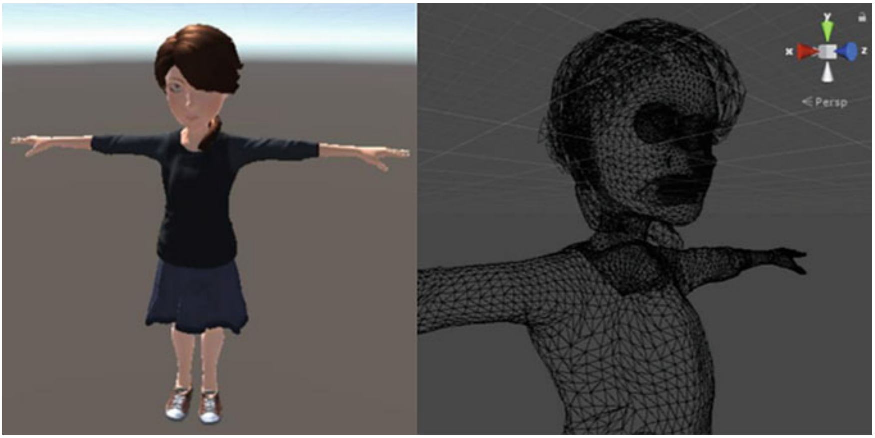

Fig. 4 Sample pedestrian model in detail

- Carefully balance performance and quality ("the visuals need to be accurate/believable, yet fast, to render in order to accommodate the performance demands of VR (60–90 frames per second)") (Maleki, 2019)
- For populated cities use the pedestrian system discussed in (Gaisbauer et al., 2020) for better performance.

Furthermore, to make PCG comparable to human-made assets (in the virtual city context), which likely enhances presence as well as the systems proposed in Table 1, we propose the following recommendations and learnings. Use parameter-based PCG algorithms to receive virtual cities that are more diverse looking and therefore like "human-made assets"[5] by (1) using a large enough number of different and diverse city tiles using random parameters for the city assets (e.g., buildings, blocks, streets, and sidewalks), (2) avoid ghost cities by populating the city with, e.g., randomly parked vehicles and humans, and (3) using a large enough number of different looking individual city assets, e.g., parked vehicles, humans, and foliage. In the ECD TNG for (1) we generated the city tiles during start-up of the Unity game using different random seeds for each tile, for (2) we populated the city with randomly parked vehicles and humans but still missing is a traffic AI system and a traffic light system, and for (3) we used 18 different 3D models for the parked vehicles and nine different models for the human pedestrians. A sample pedestrian model from (Gaisbauer et al., 2020) in detail can be seen in Fig. 4 and example 3D models for each asset are displayed in Fig. 5.

[5]For example, in the video game Grand Theft Auto V the cities were made by human artists which leads to high realism but also means a lot of time and effort in comparison to PCG content. "Los Angeles was extensively researched for the game. The team organised field research trips with tour guides and architectural historians, and captured around 250,000 photographs and many hours of video footage." (Wikipedia Contributors, 2020).

Fig. 5 Examples of the 3D computer graphics models used to populate the city (from left to right: pedestrian, vehicle, and foliage). Pedestrians and foliage are expensive to render because they have many polygons

5 Conclusion and Future Work

The main contribution of this paper is a performance study that tests whether two different virtual cities are VR ready out of the box on a recommended specification machine. The baseline versions of ECD TOV (see screenshots in Figs. 6, 7, 8 and 9) and ECD TNG (see screenshots in Figs. 10, 11 and 12) without pedestrians and parked vehicles (but with foliage in the case of ECD TNG) are both VR ready. Reducing the city tile size by half resulted in a much better performance in general.

For future work, an improvement of the pedestrian system described in (Gaisbauer et al., 2020) could be envisioned that makes the walking humans more intelligent, i.e., so that they walk on predefined waypoints instead of just in random directions. This way, the simulation of the virtual city should convey even more the "feeling of being there," which is associated with presence in VR. Also, a traffic AI system that mimics the daily traffic of vehicles in a modern city and a traffic light system is on the list of future work items and shall be tackled in the next iteration of the project.

Appendix

See Figs. 6, 7, 8, 9, 10, 11 and 12.

Fig. 6 The look and feel of 100 pedestrians spawned in a radius of 100 m while driving through the city in Endless City Driver (TOV)

Fig. 7 Pedestrians at night while driving through the city in Endless City Driver (TOV)

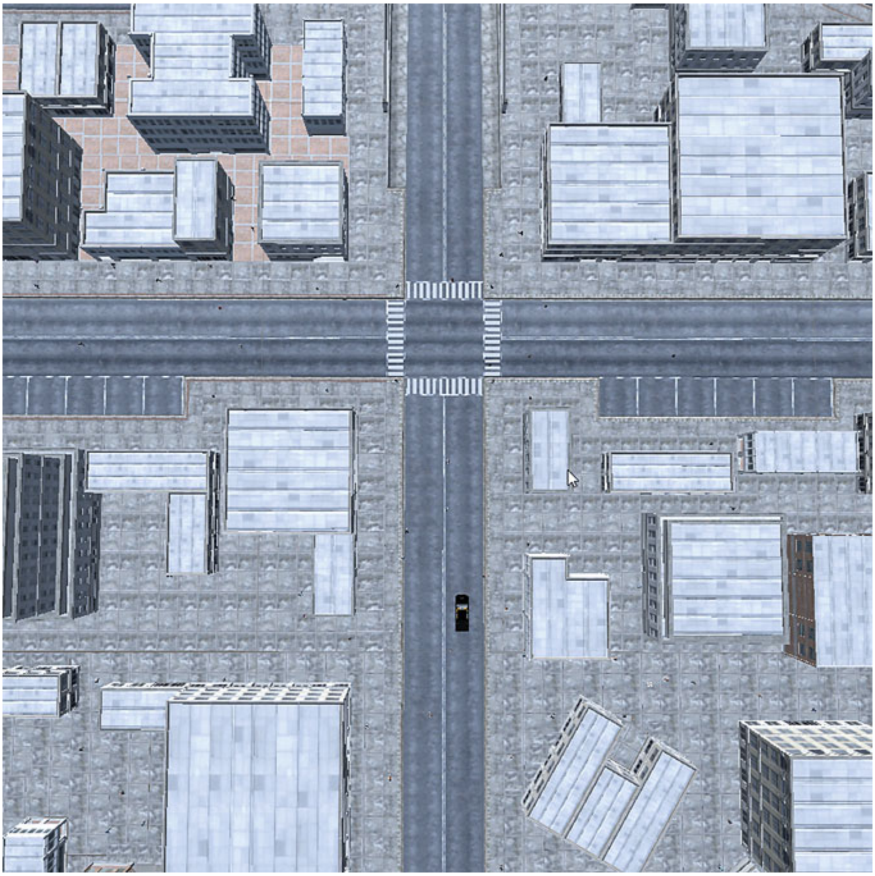

Fig. 8 Bird' s-eye view of the pedestrians spawned around the car (little dots) in Endless City Driver (TOV)

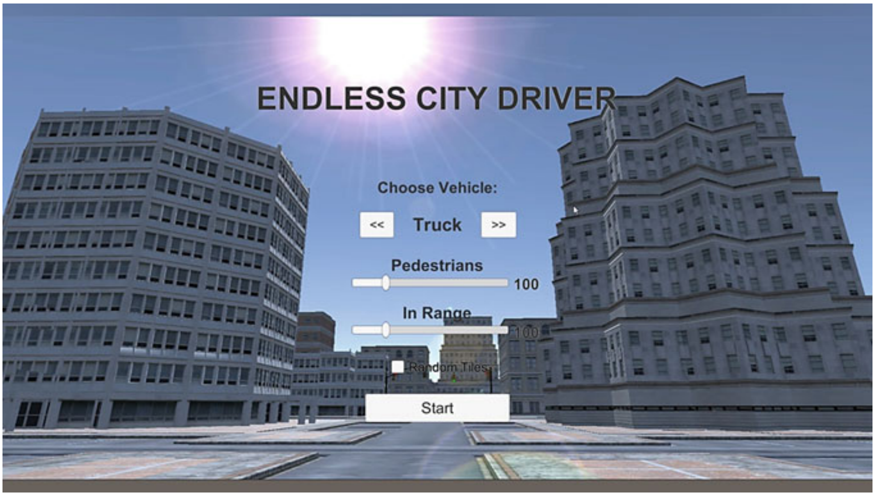

Fig. 9 The main menu of Endless City Driver (TOV)

Fig. 10 The look and feel of the randomly parked vehicles while driving through the city in Endless City Driver (TNG). Early feedback was that the city looks like a postapocalyptic ghost town and to counteract that we added the randomly parked vehicles, which also increases the presence ("feeling of being there") for the user

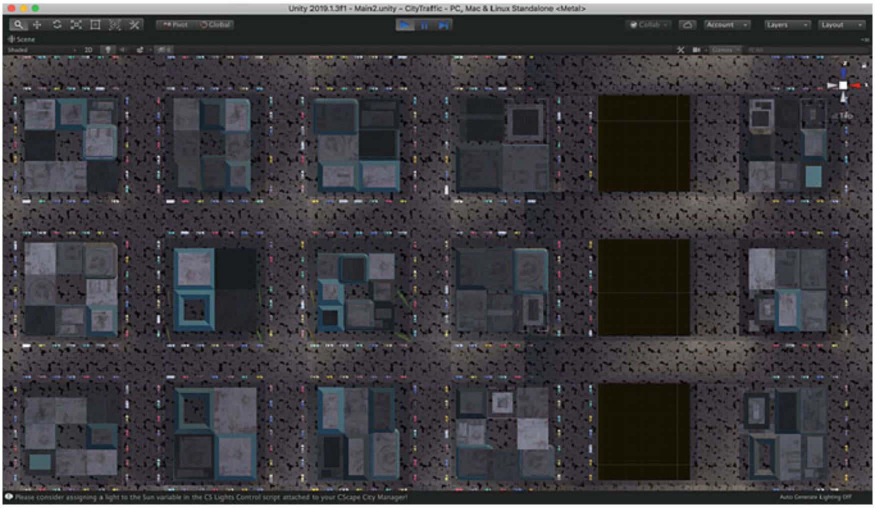

Fig. 11 Bird' s-eye view of the procedurally generated randomly parked vehicles in the Endless City Driver (TNG). There are 4200 vehicles present in the 6 × 6 city tiles, which is computationally expensive but adds to the realism and presence of the living city, avoiding a ghost town. This image represents only a subarea of one city tile with 15 city blocks visible and the parked vehicles around each city block (coloured spots) with a part of the river seen on the right flowing from the top to the bottom

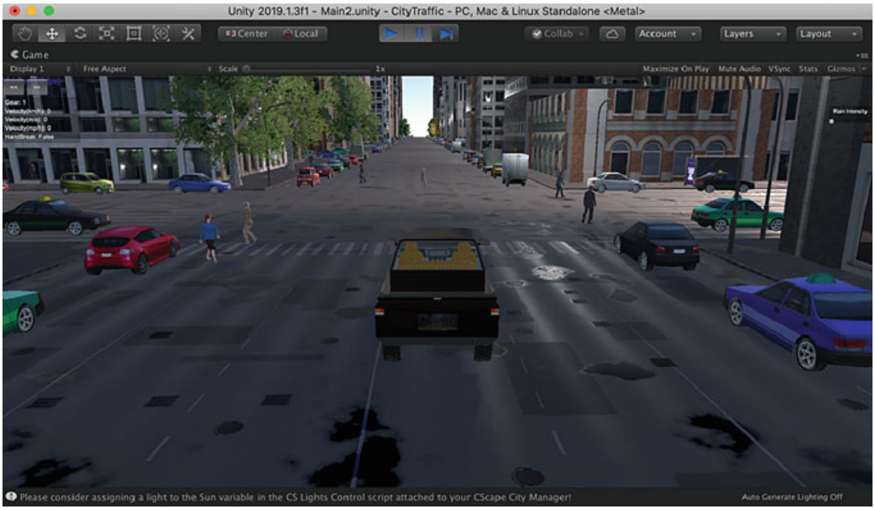

Fig. 12 Some pedestrians are walking on the sidewalks using the improved pedestrian system from (Gaisbauer et al., 2020). A sprawling and living city wsith pedestrians walking randomly around and randomly parked vehicles also including foliage was the goal of the ECD TNG project to convey the "feeling of being there" (i.e., presence) for a visitor

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A-UDT: Augmented Urban Digital Twin for Visualization of Virtual and Real IoT Data

Seungyoub Ssin, Hochul Cho, and Woontack Woo

Abstract This paper introduces a method for developing Augmented Urban Digital Twin (A-UDT) for virtual and real Internet-of-Things (IoT) visualization and its benefits. It presents a method for generating virtual data using the Virtual IoT (VI) based on real IoT data, which can be used with cloud services. An urban digital twin is developed to find and simulate various problems arising in the city by extracting and visualizing data of the city. Designing urban digital twin has some challenging issues such as the difficulty of processing environmental information in real-time due to the absence of IoT support. This absence of IoT support can make problems like developing urban digital twin without knowing the types and scope of visualization. To overcome this limitation, we propose the augmented city miniature that uses generation system, process, storage, and network system of the component that generates VI with the same data structure as real IoT to generate and send data, and it simulates information on a 3D geographic map by sending the generated virtual data to the visualization part using Augmented Reality (AR). Urban digital twin based on the virtual data can make various simulations of city visualization that can be performed to discover required IoT and reduce development costs. A-UDT system can be applied to monitor and simulate diverse environmental information such as air quality, energy efficiency, object movements, and temperature distribution.

Keywords Digital twin · Smart city · IoT · Augmented reality · Visualization · Simulation · 360 images

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1 Introduction and Literature Review

Until now, Augmented Reality (AR) technologies have mainly been developed by the entertainment industry and researchers for pure research and short-term services (Nguyen & Meixner, 2020). In the Fourth Industrial Revolution era, attempts have been made to use AR technologies as solutions to solve problems in diverse areas of society and for the development of various industries (Nunes et al., 2017; Pereira & Romero, 2017). In the future, AR technologies will be applied in various industries in a city and used as a tool that manages and monitors diverse urban spaces (Kim et al., 2017; White et al., 2019). The AR technologies for managing and monitoring urban space can be harmonized with digital twin which is a virtual representation of the real world containing all the information and knowledge of it, in order to collect city data in real-time (Schroeder et al., 2016).

However, an initial Internet-of-Things (IoT) support is absent in the digital twin development of a city that uses city data; thus, environmental information to be visualized is hard to be determined. It is one of the challenging issues to develop urban services using AR techniques (Ham & Kim, 2020). This rise in ambiguity leads to the time delay of AR simulation system developments, composed of data platforms and digital twins based on IoT (Kaur et al., 2020). Virtual IoT (VI) can be an alternative by supplementing the problems arising from the absence of real IoT. With VI, a problem may occur in the development of digital twins dependent on the information of IoT because the definitions and development methods of initial VI are not clear (Perera et al., 2014).

This paper proposes the A-UDT system that uses a virtual-city miniature using VI as a method of overcoming the ambiguity and time delay in the development of AR digital twins of a city constructed using 3D maps. A virtual-city miniature consists of three layers in the early development: IoT system, cloud system, digital twin using AR technologies. These layers are constructed using VI in the early development stage when there is no real IoT and use the virtual simulation data of VI to facilitate the development with a data structure similar to real IoT without a development time delay. Furthermore, with respect to digital twin developed for the simulation of environmental information using VI, the VI domain is replaced by real IoT after the real IoT is supported. Hence, real data are applied to the digital twin without time delay in development.

As well as visualization of a macro-perspective with city miniatures, we adopt 360 images visualization techniques as a micro-perspective. 360 image-based visualization shows person-view, which shows more detail on urban structures with realistic expression (Rhee et al., 2017). Further, the system structure of a virtual-city miniature is examined in detail.

Figure 1 shows the concept of the A-UDT system with an example of use cases at home. A person in the living room uses the A-UDT system with a Head-Mounted Display (HMD) to check the trajectory of movement and useful information by watching the city miniature augmented on the table. The person monitors activities

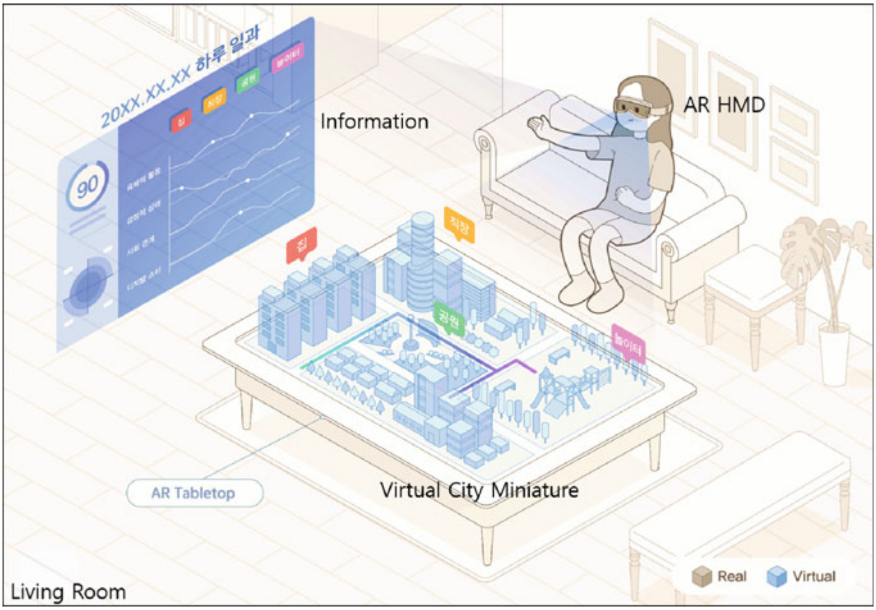


Fig. 1 The concept of the A-UDT application

of the past day with an augmented graph generated from IoT like a smartphone as a GPS device.

2 Smart City Services Based on A-UDT

The final goal of A-UDT is to improve parts of smart city services which are management, play, work, and life. In this paper, we depict urban digital twin can provide useful information for daily life, effective collaboration in the workplace, entertainment in urban space, and the management of problems that are difficult to recognize. Figure 2. shows the concept of smart city services based on A-UDT through hierarchical layers. In A-UDT, the digital twin is constructed by the real world and it consists of virtual city miniature, Virtual IoT data, real IoT data, data platform, AR visualization.

For a virtual-city miniature, commercial cloud services, such as Microsoft Azure, AWS, and Google Cloud, have separate integrated processing parts for IoT, such as MS Azure's IoT Hub and IoT Edge Devices ("IoT Edge: Microsoft Azure", 2020; "IoT Hub: Microsoft Azure", 2020). This paper provides a description based on MS Azure. An IoT Hub in cloud services controls the bidirectional communication for transmitting data to the data platform and manages IoTs connected on a large scale.

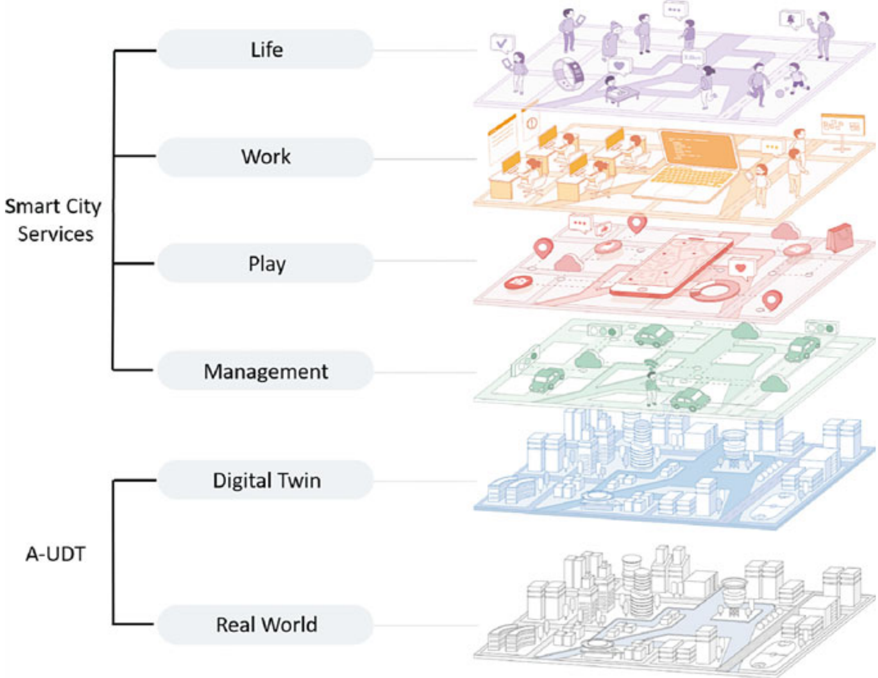


Fig. 2 The concept of smart city services based on A-UDT

Meanwhile, the IoT Edge Devices part performs the functions of authenticating and controlling all types of IoT devices connected to the cloud service.

VI is also explained using MS Azure's device simulation as an example ("Device simulation solution—Azure," 2020). The VI part is mainly divided as follows: a user-script part, in which a user has defined an IoT's ID, location, signal generating cycle, intensity, direction, type, etc.; a data-generator part, which generates data according to the user definition; a processing and storage system part, which is used for temporary storage and processing of the initial data generated; a network system part, which is used for the transmission of data (Datta & Bonnet, 2017; Datta et al., 2016).

RI part uses real IoT devices and is a part that will finally be replaced or added after using the VI. It is divided into a geo-information part, which becomes the basis of location-based services, such as GPS, a human sensor part that corresponds to the location information and media information produced by people, and data produced from RI.

The data platform part corresponds to a stage of pure data beyond the stage of IoT. The data platform part is divided into aggregation, analysis, simulation, visualization, management, and storage components. The digital twin part consists of monitoring, planning, simulation, visualization, verification, and operation components.

The augmented city miniature part performs the task of constructing the miniature expressed with AR and overlapping the AR information. To express the monitoring and simulation information created in the digital twin as AR decorations, it should be possible to construct a world using a 3D map service. A map can be either 2D or 3D; however, buildings and structures constituting a city are expressed as 3D objects on the map. Furthermore, the data created by the VI and finally reaching the digital twin are simulated, and through the interaction part, new values are sometimes applied again. The data produced by the RI and received at the digital twin are provided by a variety of AR information and media services.

Through this system as explained above, diverse types of smart city services can be designed for citizens. First of all, an urban city management system can be built on the A-UDT system that visualizes the current city environment through real IoT updated in real-time and also simulates data from virtual IoT that helps decisions to change the city environment. Secondly, the A-UDT system supports development environments that can make new entertainment AR applications based on the city environment, making citizens enjoy their space anywhere with a smartphone. It can also enhance work efficiency by using remote collaboration, which can be designed from the AR system with the digital twin. Lastly, citizens' daily lives can be changed by using personalized information, including geolocation data on the urban digital twin.

3 Architecture and Design of System

This section shows the three layers of the system which are IoT system, Cloud system, and Digital Twin Layers required for A-UDT to operate as a control center for monitoring urban spaces. Figure 3 shows the relations and connections between the layers to develop A-UDT. We describe the details of five subsystems that make up the A-UDT system in Fig. 3.

3.1 Real IoT Area

Figure 4 shows a real world part in the system architecture of the A-UDT that collects IoT data from companies and institutions in various urban spaces. The co-relations of components in Fig. 4 contain a data storage to store geo-location data, Human/IoT sensing data, and authoring data through web services (Ben-Daya et al., 2019). Then, the last data is converted to JSON format and transmitted to the data platform.

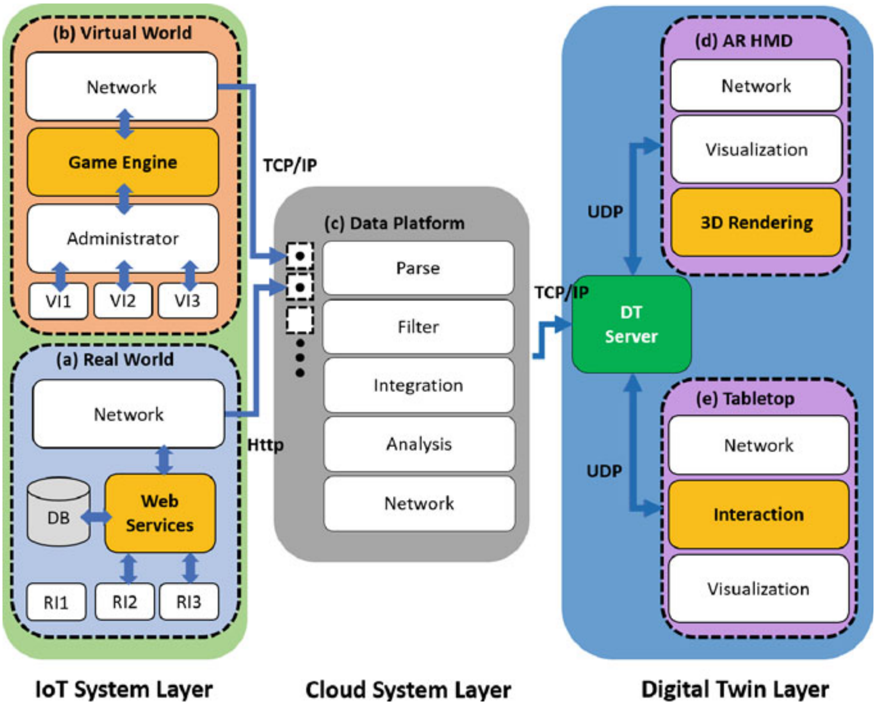
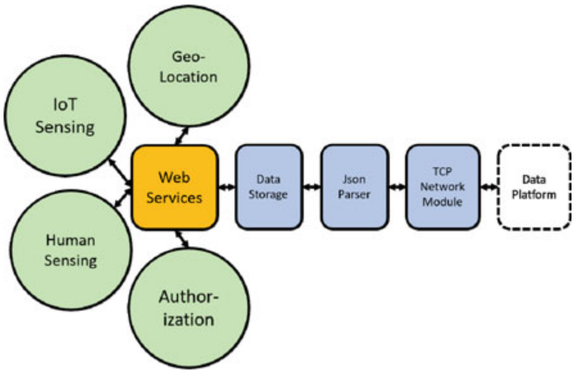


Fig. 3 The system architecture of the A-UDT

Fig. 4 The components of Real IoT system



3.2 Virtual IoT Area

It belongs to the part of (b) Virtual World of the system architecture of the A-UDT and it generates IoT data through the server's self-routine. From the relationship of components in Fig. 5, it combines geo-information data, recorded environmental data, and authoring data through a Game Engine on a 3D geo-graphical map (Datta

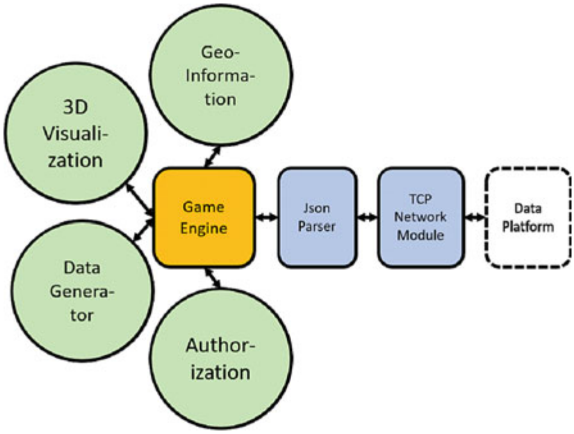


Fig. 5 The components of Virtual IoT system

et al., 2016). Then, the final data is converted to JSON format and transmitted to the data platform.

3.3 Data Platform Area

In the data platform area, the system receives heterogeneous structured data obtained from real and virtual IoT as (c) in the Fig. 3. The data platform area of A-UDT plays a role in integrating data generated in Virtual and Real IoT. Then, it serves to send data on the digital twin system using TCP/IP network.

3.4 AR Visualization Area

The DT Server in Fig. 3 connects the tabletop system with interaction and AR visualization system to browse the urban space with AR HMD like HoloLens 2. Also, it plays a role of relaying network packets generated for control from the tabletop of the Interaction area. Then, the 3D AR map in the city miniature synchronizes the position with the screen on the tabletop system and shows the objects on the AR map such as buildings, vehicles, notices/events boards, and graphs. Furthermore, we use 360 image-based visualization to show a micro-perspective view with a person-view in the urban city miniature (Fig. 6).

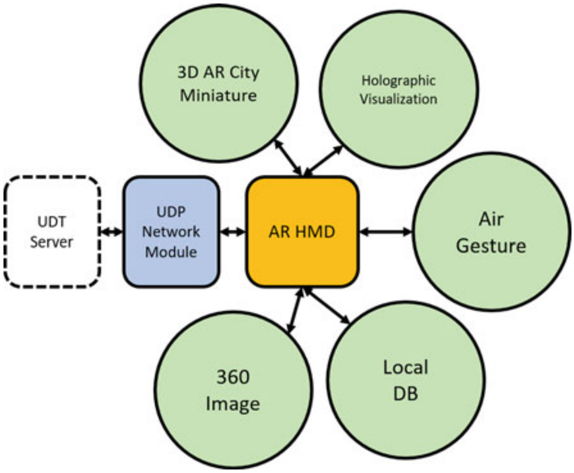


Fig. 6 The components of AR visualization system

3.5 Interaction Area

Figure 7 shows the components of the interaction system in (e) of Fig. 3 which is used by the administrators of the control center to slide or zoom the map of the specific location of the city miniature in the A-UDT, and select and track one object. The both AR HMD and Tabletop system support the same functions like drag-and-drop and selection. The 2D menu of the tabletop is used for selecting specific objects that the view of AR HMD keeps on tracking, which is especially helpful to show certain objects out of the AR HMD's view.

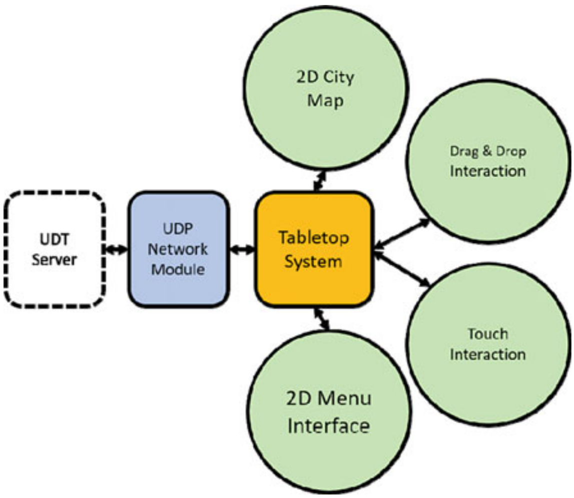


Fig. 7 The components of interaction system

4 Implementation

We implemented the A-UDT system with multiple system areas (Fig. 8). The real world information consists of time based geo-location data for vehicle movement data and building energy consumption data. The virtual world generates virtual IoT data as vehicle movement simulation data by using a Game Engine. The cloud system receives the real and virtual IoT data and transmits it to the UDT server after post-processing the two types of data. The tabletop system is used for operating the 2D map which is synchronized with AR UDT through UDP networks. AR UDT provides a visualization function that shows real and virtual IoT data on 3D city miniatures and directly manipulates the objects through air gestures of AR HMD. In this section, we describe the details of the implementation with two types of applications that are representative of micro and macro perspective views in urban spaces.

4.1 The Macro-perspective of the Urban Spaces

The AR city miniature part of A-UDT was developed to observe the urban space from a giant perspective (Lee et al., 2016; Piumsomboon et al., 2018a, 2018b, 2018c) at a look and view multiple heterogeneous IoT data (Zhang et al., 2018). We adopted this respect and represented AR city miniature as a macro-perspective view with 3D models. The IoT information is visualized on AR city miniature, such as vehicle movement and building energy consumption, and graphs of IoT analysis information are also visualized over AR city miniature.

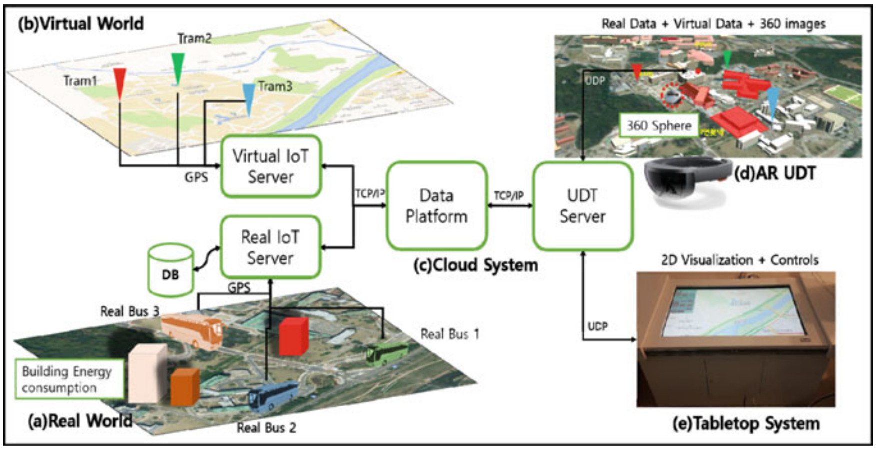


Fig. 8 The overview of the A-UDT implementation

4.1.1 Vehicle Movements

There is a service in the recent urban spaces that informs the arrival time of public transport buses at the near station. However, the current service does not support informing the number of passengers on the bus in real-time. If it is able to inform the count of passengers with IoT devices, the other public transportation can induce people in advance when the bus is occupied.

However, the data generated by the real IoT server is transmitted at one-minute intervals and the type of data is two-dimensional coordinates composed of Longitude and Latitude like Table 1. The real IoT data is expressed as points without directions because showing the direction of vehicles is difficult due to one-minute intervals that are too long term for our real-time system, especially at intersections in which the direction is rapidly changed. The number of passengers is generated virtually on the Data platform.

Virtual IoT Server reproduces simulation data of the tram that can be serviced in the future. Altitude data was created with Longitude and Latitude data to express the movement over objects which are not represented on a 2D map such as a bridge. Moreover, the vehicle's position is updated once a second to generate the vehicle direction as a vector by linking the previous position with the current location in the Virtual IoT area like Table 1.

Table 1 Real and virtual IoT data structure of vehicle movements

IoT	Parameter	Type	Images
Virtual IoT	Altitude	Double	
	Current passenger	Int	
	Max passenger	Int	
	Update interval	Int	
	Action state	Int	
Real IoT	ID	Int	
	Number	String	
	Vehicle type	Int	
	Latitude	Double	
	Longitude	Double	
	Date	String	
	Time	String	
	Engine state	Bool	

Fig. 9 The expression of building energy consumption

4.1.2 Building Energy Consumption

A-UDT was created as an AR visualization system that can be used for remote control centers that need to monitor city data (Lock et al., 2019). There are several scenarios in which a city manages trace and manages data in the city control center. For instance, we can apply to security data such as closed-circuit television (CCTV), energy consumption data in urban buildings, and fine dust concentrations in crowded areas (Zhang et al., 2018).

We have been provided real IoT data which is electricity usage of buildings recorded per hour on a daily basis from the managers of actual city buildings. The electricity usage data was provided as readable files such as csv type files. These files are integrated with the Virtual IoT server in real-time. Figure 9 shows the building energy consumption visualization system we implemented in the A-UDT.

Figure 9a shows the energy consumption in a graph when a specific building is selected. Figure 9b shows a selected building and reports the power usage status by changing color. Figure 9c shows all buildings where real and virtual IoT data is provided, changing color from white as a minimum value to red as a maximum value.

4.2 The Micro-perspective of the Urban Spaces with 360 Visualization

We used 360 image based visualization to express a micro-perspective view of the urban spaces. 360 image supports surrounding views that can make perspective views at all angles with only one 360 camera. The scene development process with 360 images is cost-effective compared to modeling high-quality 3D objects and it also

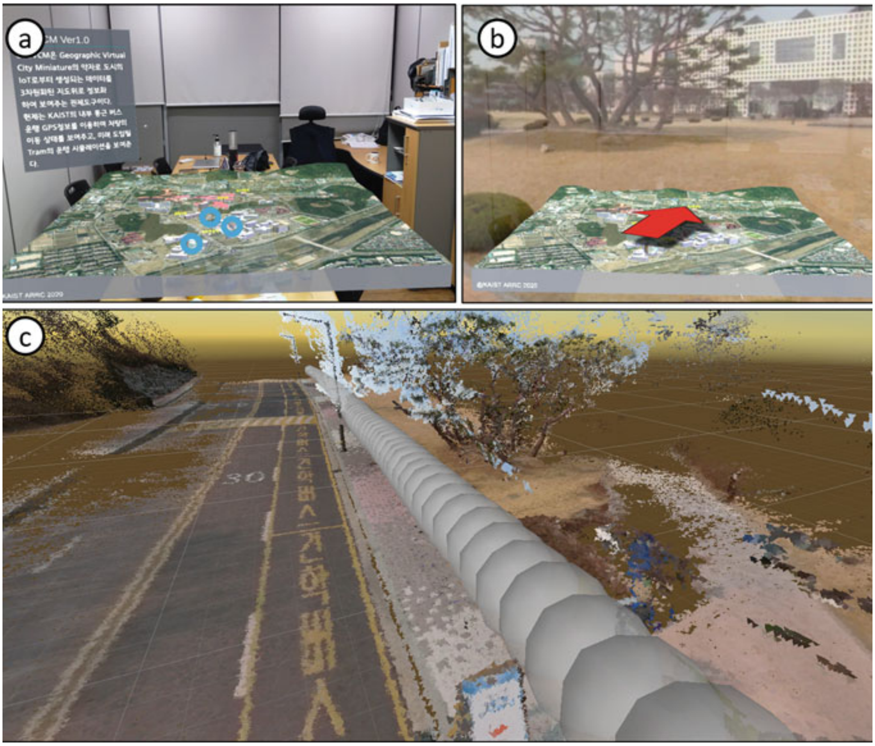


Fig. 10 360 visualization with AR city miniature in Hololens 2

gives realism with real images. So, we implemented 360 image-based visualization to show street-level outdoor visualization and indoor visualization into the A-UDT system as the micro-perspective.

Figure 10a shows a User Interface (UI) system using a sphere in the A-UDT system. We added 360 spheres mapped by 360 images and it is positioned to exactly match the geo-location of the connected scene. When a sphere that has a blue outline is clicked by air gestures of AR HMD, the scene jumps to the connected 360 visualization scene.

In the 360 visualization scene, the street-level 360 scene is visualized with a city miniature that shows the position of the 360 scene with the red arrow (Fig. 10b). We used a game engine for this 360 visualization, 360 images are mapped to spheres, and the virtual camera in the game engine is located in the sphere to render the camera's field-of-view images. Then, this rendered virtual camera's field-of-view image is visualized on Hololens 2. Furthermore, we implemented a novel-view synthesis method (Cho et al., 2019) to give freedom of movement that is able to be off the camera captured path by synthesizing novel view image. So, a person who wears Hololens 2 can walk around as well as have a free-viewpoint.

Figure 10c shows the multiple gray spheres that have estimated position and rotation information of 360 images captured and point clouds made by integrating pixels of multiple 360 images. The camera estimation and point cloud generation is processed by Structure from Motion (SfM) algorithm (Koenderink & Van Doorn, 1991) that is based on feature matching of images. Even though we do not directly visualize the point clouds to a user, we use it to give the freedom of movement by synthesizing novel view images with estimated camera poses.

4.3 Interactions Using Tabletop System

A-UDT is a tool designed for city managers to easily access city information and monitor necessary information in the control center. Therefore, we needed to develop the UI to be easily accessible to non-technical experts. It is necessary to give a comfortable, less tired touchable feeling to those who are not entirely adopted in-air gestures (Ssin et al., 2017, 2019). The interaction system with the tabletop in the A-UDT is designed to control the AR city miniature using the touch and drag-and-drop functions of the tabletop's digital screen.

If the tabletop system connects to the UDT server in Fig. 8, the UDT server transmits the sophisticated data received from the Data Platform to the tabletop system. The tabletop system represents the 2D information on the screen as the information combines the object lists with the position and state data of vehicles and buildings. The selected item in the 2D menu on the screen is transmitted to the AR city miniature through the UDT server. The AR city miniature presents the city information as a 3D visualization in the HoloLens 2 (Lee et al., 2016).

Figure 11a shows a user is using the touch function of the tabletop system. The geographic map under the 2D menu can be drag-and-drop for sliding the map, and the 2D map position is synchronized the location and zoom in/out level with them of the AR city miniature. Figure 11b presents that a user is selecting a building directly using the ray-casting function in HoloLens 2.

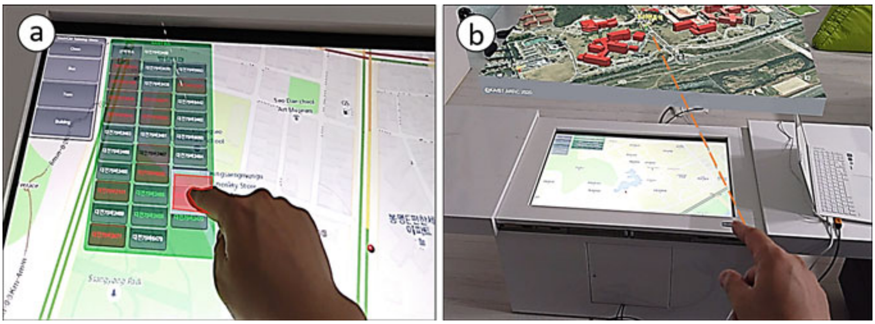


Fig. 11 The interaction with Tabletop system

5 Discussion and Conclusion

The goal of A-UDT is to develop an urban digital twin of a city for monitoring and simulating the city data. VI is used as substitutes of real IoT in the early stage of development and plays a role in pre-design of smart city services. The advantage of A-UDT can be listed as follows:

- Increasing IoT application and development speed: Determining which IoT information should be visualized in the initial development stage of the digital twin of a city is a critical factor. Moreover, the use of VI can improve the development speed because results can be produced immediately.
- Easy testing for heterogeneous IoTs: As VI can be used to produce various IoT in software, IoT can be tested widely when developing a data platform. Furthermore, if the same data structure as real IoT, then the VI can be easily replaced when the real IoT is ready.
- Visualizing simulation of the city environment: If a urban digital twin of a city is fabricated using VI, it is possible to simulate IoT data that has not actually occurred in real IoT.
- Monitoring to help understand urban circumstances: The final goal of a virtual-city miniature is the production of an urban digital twin of a city that facilitates the investigation and understanding of the urban circumstances. The environment of the entire city can be browsed by viewing the city at a glance in 3D city miniature.
- The cost-effective development process of an urban digital twin: Constructing real IoT in a city is installing hardware with high costs, which does not guarantee the effectiveness of IoT compared to the cost. VI can reduce such a waste of developmental costs and time.
- Realistic visualization of a micro-perspective with 360 visualization technique: Monitoring street-level and indoor view with realistic 360 visualizations as a micro-perspective. The streaming 360 videos can support real-time monitoring systems of each urban space that the manager would like to look into in detail.
- Real-time pedestrian and vehicle reconstruction from 360 visualization: 360 visualization can be applied for reconstructing pedestrians and vehicles in the streets by using 3D pose estimation algorithm as a real IoT, which can make moving objects in the urban digital twin. This information can be used as diverse types of applications such as traffic analysis, parking space information, passenger information of transportation.

When VI is used in a virtual-city miniature, a system load test can be conducted as a performance test. Unless real IoT sensors are constructed and operated, it is usually difficult to simulate how much IoT data are produced (Balakrishna et al., 2020). In this case, VI can support the load test of a server quantitatively.

Real smart services support the visualization of IoT data on the AR 3D map, but the final goal is to discover the usefulness of services to be provided to the citizens of a city through their visualization. For example, the air quality of a city can be visualized for a manager by using the information received from IoT, and a service can be provided for the citizens to find optimal moving paths by avoiding places of bad air quality on AR devices. Hence, various tests can be performed using A-UDT based on VI to discover smart services using IoT for citizens.

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Immersive Technology in Smart Cities, Architecture and the Industrial Sector

Virtual Reality and Artificial Intelligence: Co-creation Process Between Consumers and Firms in an Area of Smart Cities

Mónica Ferreira, Sandra Maria Correia Loureiro, and Hélia Pereira

Abstract The aim of this study is twofold: provide an overview of the virtual reality and artificial intelligence conceptualization and applications and propose a framework of consumer -firm experience process in the context of smart cities. The framework will give a novel perspective on the topic and provide theoretical and contributions.

Keywords Virtual reality · Artificial intelligence · Customer experience · Co-creation · Integrated marketing communications

1 Introduction

Virtual Reality (VR) and Artificial Intelligence (AI) have benefited from a constant presence in the front stage of the top technological breakthroughs due to their potential contribution in the Marketing field. This growing interest to understand the potential of VR and AI and as a new way to attract customers and enrich their experiences led to this study. Using the Integrated Marketing Communications concept, the final goal is to discuss the extent to which experiences using Virtual Reality and Artificial Intelligence may impact a customer experience in three different points of the customer journey: pre-purchase (brand associations), purchase (intention) and post-purchase stage (brand loyalty).

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Firms are forcing to transform the communication process due to the proliferation of new communication tools has forced firms to choose the most appropriate combination of communication platforms to deliver a stronger message consistency and also to allocate the marketing budget over these efficiently. For such, it is necessary to adopt a "360-degree view" of consumers to get a complete and potentially full understanding of their behaviour in all touchpoints with a brand (Kotler & Keller, 2012).

Virtual Reality is a technology capable of placing the user inside to a simulated environment. The interaction with 3D graphics, instead of viewing a screen in front of them, is the most immediately-recognisable component of VR. With the huge advancements in this technology, VR has recently become more associated to an immersive VR experience which includes the use of a Head-Mounted-Display (HMD) to immerse the user into a complete 3D artificial world.

In 1986, Geoffrey Hinton discover the technique behind the current excitement of AI—the deep learning—being considered "the father of deep learning" (Somers, 2017). However, due to the inefficient computer power at that time, the enthusiasm with AI was asleep temporarily and only in the last decade with the advances of technology, companies like Alphabet, Amazon, Microsoft, IBM, Facebook, Apple and three giants companies from China—Tencent, Baidu and Alibaba—have reborn the field (The Future Today Institute, 2018). Some authors say the current generation is assisting to the 4th industrial revolution, others, named it *the era of computing* (The Future Today Institute, 2018). In fact, AI comes to rethink and to revolutionise the businesses processes in four domains (Microsoft & EY, 2018).

Another related technology is augmented reality (AR), as an interactive experience of real-world environment, where the real world is enhanced by computer-generated perceptual information. Experiences with the support of VR, AR and AI have provided some of the most successful experiential marketing campaigns, leading to growing adoption of these technologies in brands' marketing strategies. However, the opinions found about the potential of VR, AR and AI in this field differ. A problem which many business leaders are interested in is to figure out if both technologies are just a trend or can be considered as a sustainable marketing tool like social media already is. Also, most of those who agree that we are on the verge of immerse change, are struggling how VR, AR and AI contents fit into their future campaigns (Dell Technologies, 2018). An important topic within the marketing field is the concept of Optimizing Media Strategy.

The aim of this study is twofold: provide an overview of the virtual reality and artificial intelligence conceptualization and applications and propose a framework of consumer -firm experience process in the context of smart cities. This paper presents and suggest that these technologies represent valuable opportunities in Marketing and that the type of experiences addressed in are more prone to instil action (purchase stage) than to build brand associations (pre-purchase stage) or brand loyalty (post-purchase stage).

2 Theoretical Framework

The literature review was done based on defined key words and the databases used were Web of Science (core collection) and Scopus. Moreover, the articles analysed were all in English and were within the following categories: Business, Management, Marketing, Communication, Hospitality, Leisure, Sport, Tourism, and Psychology (web of Science categories). The articles were included in top journals of the above-mentioned categories.

The evolution of the Internet, as well as continuous technological progress, have had significant impacts on consumer behaviour and marketing strategies. These two fields had suffered and continue to undergo profound and irreversible changes. A major aspect that influenced these shifts in consumer's personality and buying patterns was the evolution of technology. In fact, it is believed that the main determinant that changed everything when it comes to consumer behaviour was the arrival of social media platforms (Lin et al., 2011). Social media changed not only the way consumers communicate with each other but also the way they communicate with brands and a positive word of mouth is considered as an indicator of intention to continue the relationship with the destination; it is also a convincing source for potential visitors (Yoon & Uysal, 2005).

2.1 Word-of-Mouth as Loyalty

The essence of word-of-mouth marketing is to reach out to abroad set of potential customers and attract considerable attention via social interactions (Li et al., 2011). Individuals share comments and a cascade of information starts. Through word-of-mouth diffusion, information can spread more quickly and easily among social networks (Li et al., 2011). Unlike direct and mass marketing, which only recognize the intrinsic value of a customer, word-of-mouth marketing additionally exploits the network effect of a customer by taking the network factors into consideration to measure the real customer value (Li et al., 2011). People are highly influenced by information received from others (Godes & Mayzlin, 2004; Roelens et al., 2016). In a social network, marketing through word-of-mouth is extremely powerful as people are likely to be affected by the decisions of their friends and colleagues (Kempe et al., 2003; Li et al., 2011). The differential point of word-of-mouth is that, when information is shared, it has more influence on the consumer behaviour. Word-of-mouth (WOM) is the most influential source of information to a customer (Keller, 2007; Roelens et al., 2016).

Empirical research confirmed that consumers rely heavily on the advice of others in their personal network when making purchase decisions (Hill et al., 2006; Iyengar et al., 2013; Roelens et al., 2016; Sadovykh et al., 2015; Schmitt et al., 2011; Vebraken et al. 2014) and that positive WOM has a positive effect on business outcomes, i.e. sales (Bao & Chang, 2014; Roelens et al., 2016; Rui et al., 2013). Word-of-mouth is not a marketing gimmicky; it brings return to companies. Appropriate marketing campaigns based on social networks could generate a significant increase in the sales amount and reduction in the promotion cost (Li et al., 2011).

When applied to the digital, word-of-mouth should be named as eWOM. Electronic word-of-mouth (eWOM) can be defined as any positive or negative statement made by potential, actual or former customers about a product or company that is made available to a multitude of people and institutions via the Internet (Hennig-Thurau et al., 2003), and has been well recognized as an effective marketing strategy to promote product sales (Chevalier & Mayzlin, 2006). Cheung et al. (2009) investigated the influencers of eWOM information credibility and found source credibility to be positively correlated with perceived eWOM information credibility. Credibility is essential, consumers trust in credible sources of information. Previous studies have been conducted to discover what are the factors influencing perceived credibility. The findings of previous studies are that individuals are inclined to use perceived source expertise and knowledge to judge the credibility of the message when the information is unfamiliar to them (Eastin, 2001; Xiao et al., 2018), the normative determinants, such as recommendation consistency and rating, significantly affect perceived information credibility in the context of electronic word of mouth (eWOM) communication (Cheung et al., 2009; Xiao et al., 2018) and the quality of the message also influences individuals' perception of the information (Xiao et al., 2018).

2.2 Customer Experience

Align with Batra and Keller (2016) theory, with the proliferation of multiple communication tools and the rise of multiple touch points, more and more firms are feeling the urgency to move away from traditional marketing toward creating memorable experiences for their customers. Instead, consumer experiences are what drives consumption, and these are getting firms' attention as a strategy to attract customers and to gain competitive advantage.

Pine and Gilmore (1999, p. 3) claim that "*…companies stage an experience whenever they engage customers, connecting with them in a personal, memorable way*". Actually, the "experience economy" developed by Pine and Gilmore has been widely used in academia. According to the authors, "while prior economic offerings-commodities, goods and services- are external to the buyer, experiences are inherently personal, existing only in the mind of an individual who has been engaged on an emotional, physical, intellectual or even spiritual level" (Pine & Gilmore, 1998, p. 99).

Pine II and Gilmore (1998) conceptualised experience as the progression of economic value. *"An experience occurs when a company intentionally uses services as the stage, and goods as props, to engage individual customers in a way that creates a memorable event."* (Pine & Gilmore, 1998, p. 2). That is, an experience is a differentiated offer with a premium but worth pricing which is personal and memorable. According to them, companies only achieve the stage experience when they are charging customers for it, instead of charging them for goods or services.

Other researchers have defended a broader view of customer experience. Schmitt (1999) termed it as Experiential marketing. The first and most important assumption of experiential marketing is that a customer is a rational and mainly an emotional human being who values functional attributes but also pleasurable experiences. As opposed to traditional marketing, experimental marketers consider that consumers seek pleasurable experiences. Therefore, marketers, to be successful, need to be able to deliver a desirable customer experience using technology, brands, and integrated communication (Schmitt, 1999). According to the author, consumption is perceived as a holistic experience and there are rational and emotional drivers in consumption. According the Strategic Experiential Modules (SMEs) from Schmitt (1999) a consumption experience can exploit five different reactions: a sensory experience through sound, touch, taste, sight and smell (SENSE); an affective experience that appeals to customers' emotions (FEEL); a cognitive experience that enhances intrigue and provocation with the creation of a problem solving (e.g. "Does it make sense?") (THINK); a rational approach to changes in lifestyle and behaviours (e.g. Nike with "Just Do It") (ACT); and finally, a social-identity experience that relates the person to a reference group or culture (e.g. the brand Harley-Davidson) (RELATE) (Schmitt, 1999).

Within the tourism and hospitality industry, the importance of customer experience has also been highlighted by several scholars. Moreover, the experiential concept has been widely examined in tourism and hospitality studies as experience is one of the core benefits of service offers, due to its specific characteristics (Manthiou et al., 2016).

2.3 Customer Journey

Lately, Lemon and Verhoef (2016) developed a theory where a multidimensional and dynamic process defines a customer experience. In a far-reaching perspective, customer experience combines "*the customer's cognitive, emotional, social, and spiritual responses to all interactions with a firm*" (Lemon & Verhoef, 2016, p. 70).

Marketers name that dynamic process as the "Customer Decision-Making Process". Nowadays, the classic "purchase funnel" or the AIDA model by Elias St. Elmo Lewis (1898) (**A**wareness, **I**nterest, **D**esire, and **A**ction) are outdated. The consumer "path to purchase" is any more a hierarchical process, but a non-linear and circular one in which consumers before to select a brand, modify their first choices as often as they want until to find the product/service which satisfies them more. Researchers from *Mckinsey and Company* so-called it as a "Consumer Decision Journey Circle" (Lemon & Verhoef, 2016). Actually, Batra and Keller (2016) in their framework developed a Dynamic, Expanded Consumer Decision Journey with 12 potential steps: (1) Needs/Wants; (2) Is Aware; (3) Considers; (4) Searches; (5) Likes/Trusts; (6) See Value/Is Willing to Pay; (7) Commits/Plans; (8) Consumes;

(9) Is Satisfied; (10) Is loyal/Repeat Buyer; (11) Is Engaged/Interacts; (12) Actively Advocates. The first stage is pre-purchase which consists of the full experience before purchase. It contains the (1) feel of a need, (2, 3, 4) the willingness to know more about it/search for more information and finally (5, 6) to consider fulfilling that need with a purchase. Then, the second stage is the purchase itself where (7, 8) customer gets in contact with the brand through behaviours like choice, ordering and payment. In this stage, the marketing mix elements have been considered relevant to influence purchase intention. Last but not least, the post-purchase stage that encompasses the possible behaviours that follow the usage or consumption (9, 10, 11, and 12): (dis)satisfaction, repurchase, worth-of-mouth, (dis)engagement or loyalty (Lemon & Verhoef, 2016).

2.4 Tourism Experience Co-creation and Engagement

Information and Communication Technologies (ICTs) lead to a paradigm shift in the tourism industry, which Buhalis and Jun (2011) called as *e-tourism*, which changed the practices adopted by tourism service organizations and the functions of the stakeholders involved in the process. According to Živković et al., (2014, p. 758), "*from the 'static web' and unidirectional flow of communication until 'the second phase' of web 2.0 and bidirectional communication, new levels of relations have started up.*" It was due to the appearance of Web 2.0, social networking and mobile internet that value co-creation started to gain more relevance and the customers stopped being a passive subject of the producers (Prahalad & Ramaswamy, 2003), turning into connected consumers searching for valuable and extraordinary experiences enriched by technology (Tsiotsou & Ratten, 2010). According to Kaplan and Haenlein (2010), it was the appearance of a subdivision of Web 2.0 applications, called *social media*, that led to the major repercussions of Web 2.0, i.e., the empowerment of the consumer and the enlargement of Word of Mouth, being the Web 2.0 "*not only a mass medium, but a platform that has a much broader role and function than any of the traditional mass media.*" (Fotis, 2015, p. 38).

Actually, tourists are using the information and communication technologies (ICTs) to analyse, compare, evaluate, and choose the destination that better suits their expectations, desires, and needs, thus gaining control over the process (or over part of it), responsibility for their choices and feeling more independent (Berrada, 2017). As a matter of fact, according to Tussyadiah and Fesenmaier (2007), ICTs have fundamentally altered the nature of tourism experiences, i.e., experience co-creation has become richer and been multiplied (Gretzel & Jamal, 2009).

Information systems bring a chance for organizations in the tourism industry to stablish a closer and more meaningful collaboration with the consumers, which leads to the development of personal, uniquely designed, compelling, innovative and valuable experiences (Berrada, 2017; Neuhofer et al., 2012). That being said, technology provides a platform of communication (Buhalis & Law, 2008) that leads to the co-creation of a more valuable and innovative experiences from not only an *economic-functional* but also *a cultural and ideological perspective* (Cova & Dalli, 2009) by spreading their circle of activity to the virtual space (Neuhofer et al., 2012) and guaranteeing a superior level of information, enthusiasm, transparency, and centricity in the tourist in the co-creation process (Chathoth et al., 2016).

According to Watson et al. (2004), ICTs are a crucial tool when it comes to comprehending the three major stages of tourism experience in which value is consumed and the tourist connects with other actors, like friends, family, community, firms (Andrades & Dimanche, 2014), which are: planning (before the trip), tourism (during the trip), and memory (after the trip). During the *first stage*, the tourist, who is globally connected thanks to the tools provided by the Internet, gathers new information about the touristic destination (like what to visit, where to eat and sleep, and so on) by using the diversified web sources and the interactions with friends, family members or other tourists, before "purchasing" the tourist experience. It is also during this first stage that tourists interact with the reservation systems and other service providers through the Internet (Watson et al., 2004). In the *tourism stage* tourists use their mobile devices to access information anywhere and in real time about the destination and the available services, thus expanding to the usage of ICT's service while moving (Schmidt-Belz et al., 2003), in order to adjust activities and give recommendations. This means that mobile technologies lead to the enhancement, intensification, and co-creation of experiences in any place and at any time (Neuhofer et al., 2012). Finally, in the *memory phase* the process turns to a C2C tourism experience co-creation, since tourists extend their trips in time and space by sharing their stories and experiences at the destinations in person or using ICTs, after reflecting on the experience they lived and thinking about the good memories (Watson et al., 2004; Caldito et al., 2015). According to Buhalis et al. (2012, p. 550), the tourism experience becomes "*an almost real-time shared adventure that is co-constructed with the connected social network of tourism providers, friends, followers and other tourists online*".

As stated by Carù and Cova (2003), over the past decades several experience definitions have been developed, from a sociological, psychological, or anthropological view. In fact, services are becoming more commoditized and staging experiences is the "*progression of economic value*" and the next competitive battle for Business to Business and Business to Consumer industries, i.e., the most advanced mean to generate value (Grönroos, 2008, p. 4; Pine & Gilmore, 1998). Thus, Prahalad and Ramaswamy (2004) state that the satisfaction of the consumers comes from turning an *essentialist* notion of the product to a *relational* notion, in which the product is in an experiential network. This means that innovation becomes more about experiences, rather than products, in a way that it is in the field of experiences that consumers can co-create customized outcomes, thus retaining their individuality and producing unique value (Prahalad & Ramaswamy, 2004). Morgan et al. (2010) also claimed that customers are no longer looking for simple products and services, which are currently more exchangeable and replicated, but rather for the experience attained by the consumption of products and services.

Due to the changes in the market and customers' needs the tourism strategies keep evolving, nonetheless the main objective is always to assure customers' satisfaction with every element of the tourist experience and the consequent loyalty to the destination (Berrada, 2017). A study conducted by Buonincontri et al. (2017), on the main antecedents and consequences of the co-creation of tourism experiences, lead to the conclusion that this process can "*influence tourists' attitudes on spending more money for a more experiential and co-created visit of a destination*" (p. 274), because of the level of satisfaction and happiness that comes with the co-created tourism experience. Besides, the satisfaction that comes from this innovative process also leads to a positive word-of-mouth and a positive destination's image (Buonincontri et al., 2017).

Hence, the tourist experience co-creation is a crucial strategy for the tourism industry and tourism destinations and "*an innovative way to live differently the tourist experience*" (Berrada, 2017, p. 18). In fact, if tourism firms intend to innovate, they need to integrate the customers in the process of value creation instead of focusing on their internal resources or their market position (Berrada, 2017). According to researchers like Eraqi (2011) and Rihova et al. (2014) tourism experience co-creation lets tourist do things instead of just looking at them, establish relationships and connections to other people, explore "multi-sensory" environments, and participate in experiences for self-development. In contemporary times, tourism experiences can be enhanced, generate a higher level of value and be more personalized not only by experience co-creation but also by using technology, which may also lead to the creation of new kinds of tourism experiences (Neuhofer et al., 2012).

In the current proposal, researcher intends to demonstrate that the co-creation of value will be more effective if tourists become engaged with the whole experience. Indeed, the concept of engagement has been used in several fields like marketing and tourism, where the meaning start to emerge mainly, after 2005 (Brodie et al., 2011).

Several definitions for customer engagement have been developed over time. For some, the concept was interpreted as being a psychological process which drives customer loyalty (Bowden, 2009). For instance, "…the psychological state that occurs by virtue of interactive, co-creative customer experiences with a focal agent/object (e.g., a brand) in focal service relationships" (Brodie et al., 2011, p. 260). Others follow the concept of customer brand engagement, which was defined as "the level of an individual customer's motivational, brand-related and context-dependent state of mind characterized by specific levels of cognitive, emotional and behavioural activity in direct brand interactions" (Hollebeek, 2011, p. 790). Another group of researchers are guided by Kumar and his colleagues (e.g., Gupta et al., 2018; Kumar & Pansari, 2016) and consider engagement from both points of view: customers and firms. In this last situation a whole "new" theory is emerging, where engagement is embedded in relationship marketing field. The current research will follow this last approach.

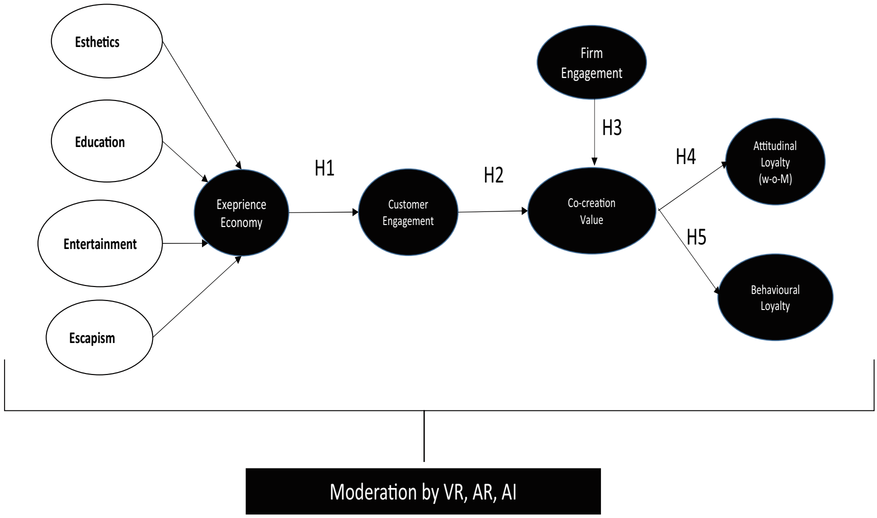

Fig. 1 Proposed model

2.5 *Proposed Hypotheses*

The conceptual framework (see Fig. 1) is proposed with the support of the field of relationship marketing and the emerge theory of customer engagement (e.g., Gupya et al. 2018; Kumar & Pansari, 2016). We claim that guest experience -evaluated through the four facets suggested by Pine and Gilmore (1998) and adapted to the hospitality context by Loureiro (2014) will enhance customer engagement with the hotel experience. Once engaged, guest will tend to be more active in contributing to the co-creation process of developing new experiences or improving the existent ones (e.g., Brodie et al., 2013; Gupya et al., 2018; Morgan et al., 2010; Prahalad & Ramaswamy, 2003).

Co-creation process represents an active interaction that could happen between guests and organizations/firms (Prahalad & Ramaswamy, 2003), Thus, firms have a role in this process and here the researcher suggests that firm engagement will contribute to the co creation process (Kumar & Pansari, 2016). As the outcome of the co-creation process, guest will become more loyal, that is, they will then to spread the word (attitudinal loyalty), mainly through online platforms, recommend to others to stay at the hotel and even be more willing to return (behavioural loyalty).

Finally, AR could play a role augmenting the lived experience and acting as moderator in the relationships between experience economy and customer engagement, as well as in the relationship between customer engagement and co-creation value. The proposed model will be demonstrated during the process of staying at the hotel. Indeed, when guest stay at the hotel, they not only experience all the environment inside the hotel facilities, but also will visit the surrounding environment where the hotel is located. Guests will try to explore, visit museums or other attractions (depending on the place) and even participate in tours. During this period, guests could use a mobile and the possibility to have access of AR. The mobile with AR can change the experience in comparison with other group of guests without AR. Therefore, the presence and absence of AR can modify the strength of the relationships between customer experience and customer engagement, as well as between customer engagement and co-creation value.

Taken all together, the following hypothesis are suggested:

H1: Customer experience (economy) is positively associated to customer engagement.

H2: Customer engagement is positively associated to co-creation value.

H3: Firm (employee) engagement is positively associated to co-creation value.

H4: Co-creation value is positively associated to attitudinal loyalty (w–o-m).

H5: Co-creation value is positively associated to behavioural loyalty.

3 Research Outcomes

In what concerns the results expected, we hope to find out, on the web reviews, more information about the IMC, engagement and co-creation that can add value to the conceptual model proposed.

From an academic perspective, this research has as main objective to bring greater clarity to the concept of communication and consequently, customer engagement during all their purchasing decision process in a digital and a marketing communication context into the context of smart cities. The teaching of marketing communication must be adjusted to what Deighton and Kornfeld (2007) called "*digital interactive transformation in marketing*". It is intended to cover a gap in the literature given since there is still a very limited number of articles, based on scientific research, focused on the bridge between marketing and new technologies, between tourism marketing and new technologies.

In business terms, ensure a better perspective of the actions to be developed in to ensure customer engagement and loyalty, naturally critical to organizations. Currently, it seems that managers have adopted a "learn by doing" attitude and, consequently, it seems that practical is in a more advanced stage than theory. In business terms, give a better perspective of the communication actions to be developed to assure the decision, naturally critical for organizations. This study addresses the dynamics involved this means as a communication tool, from the perspective of all stakeholders (media agencies, distribution channels, brands, consumers, and new media).

Finally, smart cities as a developed urban area that creates high quality of life by excelling in economy. Mobility, environment, people, living, business, and government are cities where technology is key. Therefore, more research is needed to understand the experiences in smart cities and the co-creation processes.

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Bringing Knowledge and Emotion to the Industrial Field: ETT's AR/VR Solutions

Adele Magnelli, Giovanni Verreschi, and Matteo Ventrella

Abstract The birth of the Industry 4.0 is linked to "enabling technologies", which provide significant advantages to both industry and users. Among these, a particular role is played by Augmented and Virtual Reality, which, by combining real and digital world, can optimize production, sales and user experiences. This is the goal behind ETT's AR/VR projects in the Industrial Field: immersive technologies that guarantee engagement, safe environments and innovation. Four case studies exemplify how these technologies can support the industry sector. Area X for Intesa San Paolo and NIA VR app for the National Fire Brigade bring the user into a safe and totally digital world; while the automotive production and rental service Car Server apps merge real and digital world.

Keywords Industry 4.0 · Augmented Reality · Virtual Reality · Immersive Technology · User Experience

1 The Role of New Technologies in the Industrial Sector

Digital technologies are profoundly transforming not only people's daily lives but also industrial sectors, and that explains the increasing talk of the Fourth Industrial Revolution or Smart Manufacturing. In this regard, the Polytechnic University of Milan provides a clear definition: "This new wave of digital innovation in operational processes follows the first one linked to the steam engine (late 1700), the second to mass production (early 1900) and the third since the advent of the first computers in factories (1960–1970)".

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We can trace, therefore, a trend in industrial automation that integrates some new production technologies with improved working conditions and increased productivity, competitiveness and quality standards.

This new context takes shape with the so-called Industry 4.0, the name of the German Government's industrial plan drawn up in 2011, which provided for investments in infrastructures, schools, energy systems, research institutions and firms to modernize the German production system and bring German manufacturing sector back to the top of the world by making it competitive at a global level.

A study conducted by Boston Consulting shows that the fourth industrial revolution is focused on the adoption of the so-called "enabling technologies". Even if some of them are to be considered "old" knowledge that have never broken through the wall of division between applied research and real production systems, today, however, thanks to the interconnection and interaction between systems, the global market landscape is changing, leading to mass customization, becoming of interest to the entire manufacturing sector.

Among the new enabling technologies, thanks to which industries increase their competitiveness, we find: Internet of Things (IoT), Big Data or Industrial Analytics, Cloud manufacturing, Advanced Human–Machine Interface (HMI).

Internet of Things is an expression used to define those everyday objects that can become intelligent, i.e. with self-identification, location, status diagnosis, data acquisition, processing, and implementation capabilities.

In the Internet of Things field, researchers consider devices with a prevalent data acquisition function (e.g. wearable devices for measuring environmental and security parameters), and in the Advanced HMI field, which is discussed later, those with innovative components in the interaction between operators and mechanical and computer systems.

Big data or industrial analytics refers to a specialization of methodologies and tools to process and elaborate large amounts of data, both in production and supply chain management. Among others, data can come from IoT systems connected to the production layer, such as sensorized and connected machinery, or from the exchange between IT systems for planning and synchronizing production and logistics flows. This includes the application of new simulation and forecasting techniques and tools to identify the information hidden in the data and its effective use to support rapid decisions.

The Advanced HMI (Human–Machine Interface) indicates the recent developments in the field of wearable devices and more generally of new human/machine interfaces, for the acquisition and transmission of information in voice, visual and tactile formats. Advanced HMI includes consolidated systems, such as touch displays or 3D scanners for gesture acquisition, and more innovative solutions such as Augmented Reality and Virtiual Reality—technologies that can make industrial processes simpler and more efficient, and which, in this context, must be considered more as a process innovation, rather than a product or platform.

These technologies in fact, now represent a new asset to support decision-making processes, product design, staff training, plant maintenance and safety control and are bringing countless benefits to companies, in terms of optimizing production processes. More specifically, AR and VR technologies make it possible to view the product in the design phases, in real scale and with natural interactions, allowing the optimisation of the design phases, anticipating problems related to the product and consequently reducing the impact on production costs. Immersive technologies also make it possible to evaluate alternative scenarios and exponentially extend the possible configurations of the product to be examined.

Virtual Reality allows immersion in a simulated environment and is able to prepare workers the best possible way in any operational scenario, in any place—thanks to mobile devices—and in complete safety. This technology, that allows active learning by doing, more effective than conventional tools, is increasingly used in the automotive industry and allows viewing cars in pre-production, without the need to physically build a prototype—with VR viewers, in fact, the user is able to navigate inside the cockpit, view all the details and evaluate other parameters—with obvious practical and economic benefits.

Augmented Reality can also be decisive in several areas, such as repairs, making the process much simpler and, more generally, safer the main stages of the production process. Specifically, thanks to the use of the latest. Augmented Reality technologies, production processes can be optimized: the use of special mobile devices allowa users in the field to superimpose digital information (infographics, images, videos, 3D models, etc.) to the real context, compared to the areas of interest.

In this way the technicians, once in proximity of the intervention area, can autonomously and in real time consult in Augmented Reality all the basic technical necessary information to carry out the planned activities.

The two new technologies, therefore, have different fields of application and in the future will allow companies, including those in the industrial sector, to achieve growing improvements in production processes, maintenance, service (which can be done remotely) and many other areas, like the working conditions of its employees. The expected benefits, however, can only materialize through the combination of the different technological solutions indicated, according to an approach aimed at systemic integration of the different technological areas, and accompanied by appropriate management choices.

The above analysis of the industrial context shows that new technologies are increasingly impacting on production processes and business models, affecting a growing number of application sectors, including industries where there is a significant growth of the use of advanced technologies in order to progressively improve the level of digitization and competitiveness. This process will lead to an environment characterized by fully automated processes that will be able to exchange data with other systems and monitor each other.

2 ETT Expertise

ETT S.p.A. is a Digital and Creative Industry specialized in technological innovation and Experience Design. It was established in 2000 and it currently employs over 100 people between Genoa headquarters and various offices in main Italian cities and London. ETT has been active for years in the New Media field, for which it creates innovative applications exploiting the potential of new technologies in contexts related to edutainment, culture, tourism, communication and marketing. It combines original design, storytelling and cutting-edge technologies to create engaging experiences for museums, corporate and public spaces. In this field, since 2008 it has over 1000 multimedia installations in about 100 museums and private customers, for a total of over 3.5 million visitors. In addition to the expertise and efficiency that ETT has developed in conceiving, designing, innovating and making new and creative projects, ETT focuses its attention on taking care of the users, with the main purpose of giving them immersive experiences. The customer and his needs are at the heart of ETT's projects, which are built trough customized design and technology solutions.

3 ETT Case Studies

With the digital revolution, the boundaries between the physical and digital world are shrinking, creating an interconnected environment where industry, machines, products, services and buyers can closely interact. The last twenty years have witnessed great advances in research and innovation in Augmented Reality (AR) and Virtual Reality (VR) environments. Virtual Reality and Augmented Reality ease collaborative engineering, generating common work environments for design equipment and for selling products and services.

Among ETT's technological solutions, in the context of using Augmented and Virtual Reality as means of conveying information, creating engagement and providing training in the industry sector, the Case Studies that stand out are:

3.1 Car Viewer, Unipolsai

CAR viewer is an Augmented Reality application that offers an innovative solution for discovering vehicles, exploring them virtually, deepening knowledge of the various models characteristics through 3D Real Time vehicle reconstructions. Clients can assess different vehicles until they find the ideal one, before they even touch it, in a simple, immediate and safe way. The application allows to visualize and interact with the model and to position it in the room where the client is, maintaining contact with the real world. The AR experience can be enjoyed through last-generation tablets or smartphones.

The automotive sector has had to shift from a product-driven to a customer-centric approach to adapt to new customer behaviour and expectations. This AR application (Fig. 1), created for the car rental services industry meets the ever growing habit of customers that begin their renting journey online to look at all the relevant information

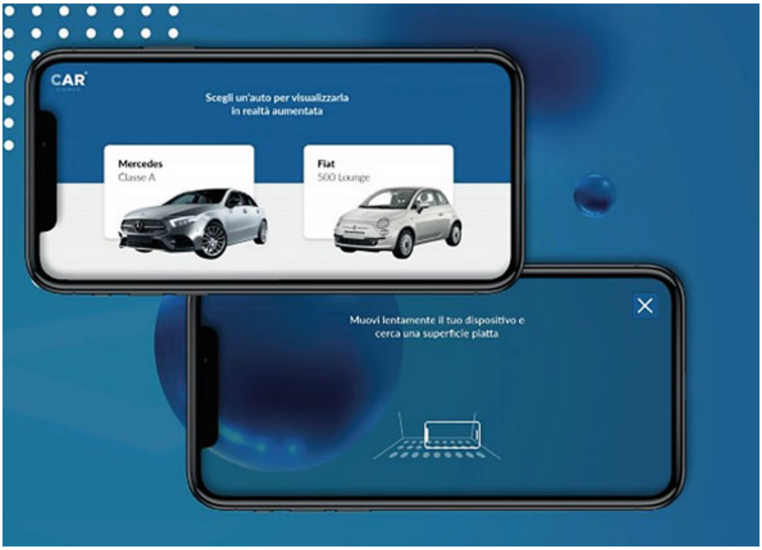

Fig. 1 The car model selection section of the AR app created for UnipolSai

at their disposal. The chance to inspect a car and its main characteristics in Augmented Reality allows to imagine the possibility, in the field of sale and rental, of being able to offer products and services to the public and in many different locations without having to physically transport the cars. Apps like this one might pave the way for using Augmented Reality to digitalize showrooms whilst bypassing the problem of limited physical inventory as it enables car rental services to show customers the complete range of models and specifications. The use of AR is already shaping automotive retail and renting by exploring different key areas that could provide competitive edge, going from increasing brand engagement to educating potential consumers.

AR can be used as a tool to better educate customers, particularly regarding technical information. The ability to overlay technical data onto real world objects, like cars, can provide customers with contextual information that they can interact with, creating a more engaging experience than the use of traditional channels like websites. Augmented Reality provides a unique way for customers to see and experience technical features in a way that they will easily understand and quickly engage with.

3.2 Lamborghini Museum, Lamborghini

The Lamborghini Museum design has been completely renovated to create a new immersive experience, taking visitors on a journey through the world of the Italian luxury brand Lamborghini, from its past to its future. The new concept of the museum has an immediate impact on visitors, using dynamic lightboxes, video walls, interactive screens and many other technological solutions.

To improve the visiting experience inside the museum journey, a mobile guide App has been developed. The new app includes an AR section that allows the visitor to interface with AR replicas of both vintage and modern cars, simply by framing the museum ticket with the device camera. Visitors are able to choose the car model and interact with it, opening the doors, turning on the lights, choosing the colour and so on.

Museums in general, and especially corporate museums, desire to increase audience engagement in innovative ways. Augmented Reality is one of the technological tools that corporate museums can use to communicate knowledge with their audiences, as Augmented Reality experiences usually invite the user to find out more about a specific subject.

AR can also represent a tool to overcome the physical location of the museum itself, creating long distance experiences that can offer an additional meaning to the one deriving from a physical visit to the museum space.

The success of this approach is linked to the quality of the contents and the applications that are going to be implemented to allow the overcoming of physical boundaries of museums. In fact, the evolutionary process of "virtual museum", started in the 90s, has not reached its pinnacle yet. With the use of technology like AR, museums can transcend their physical dimension and meet their audiences even before the actual visit. AR content like the one created for the Lamborghini Museum (Fig. 2) can be made available from home and can be used to generate audience engagement: before the museum visit, to spark curiosity and entice visitors, and

Fig. 2 The app section dedicated to AR, created for the Lamborghini Museum project

after the museum visit to awaken memories and emotions and generate positive word of mouth.

3.3 4Matic Tour, Mercedes Benz

The Mercedes 4MATIC SKI Tour event took place on the slopes of Plan de Corones, in the Alps of Trentino Alto Adige. For the entire winter season, the 4MATIC range of Mercedes-Benz was one of the leading attractions in the main Italian ski resorts.

Using Virtual Reality headsets and motorized seats, ETT has created an immersive experience that allowed visitors to be the protagonist of a Mercedes Tour. The truthfulness of the VR videos, shot in subjective point of view, was enhanced and enriched by the use of driving controllers that made the users feel like they were really driving a Mercedes car on a snowy descent.

Virtual Reality, to date, represents the most similar technology to a physical experience and the most engaging one, in terms of interaction and understanding of technical subjects. In the automotive sector, actual showrooms are undergoing the process of transformation into digital market places equipped with VR experiences. Car dealers can in fact use VR technology in dealerships to simplify car-buying experiences without leaving behind the process of in-person negotiations. Furthermore, getting potential buyers into auto dealerships is becoming increasingly difficult, as millennial customers, in particular, are resisting taking part in traditional dealer and customer negotiations.

The use of engaging and edutainment experiences like the one created for Mercedes Benz, represents a way to reach in an innovative way new potential clients, by using a technological tool that they recognise as familiar. VR experiences like this one can revolve around event tours, like the 4matic Tour, but can also be presented in car showrooms and automotive fairs, to increase brand awareness and engagement, creating strong economies on the diffusion of content created for Virtual Reality fruition.

3.4 Area X, Intesa San Paolo

Area X is an innovative edutainment space that relies on the concept of "protection", where live interactive and engaging experiences in Virtual Reality take place. Crossing the doors of the Intesa San Paolo exhibition area, a unique adventure starts, bringing the visitor to an evocative alien planet where protection is as important as on planet Earth (Fig. 3). Here, as settlers, visitors are asked to choose how to act in this new world. In three different stations is possible to explore the planet in different environments: driving a jetpack to fly among suggestive floating islands, visiting an alien housing module or driving a space rover on a journey through breathtaking 3D scenarios.

Fig. 3 The VR area set-up created for Area X project

The edutainment experience created for Intesa San Paolo Area X aims to increase the culture of protection. Thanks to Virtual Reality, visitors are invited to live interactive and fun digital representation of everyday situations: at home and away from home, on the road and in the city through different scenarios that are influenced by the choices made by the user. This edutainment technique is used to sensitize users on how to understand the possible risks and unexpected events and the consequent needs for protection for themselves, their family and their property, and the importance of conscious choices to respond to the protection needs.

The VR experience developed subtly blends reality and virtual information, making it possible to explain complex phenomena while relating them to the scale of the real environment, with a fun twist. Edutainment VR environments can be used to learn by identifying and manipulating elements. So, learning is "gamified", transformed into play, but remains anchored to real life situations while permitting solicitation of kinesthetic, learning by gesture and visual memory.

3.5 Pafa System, the Textile Machinery Industry in Virtual Reality

Virtual Reality has the characteristic of isolating the user from the real and physical context, proposing new scenarios through a totally immersive system in which most of human senses can be used. The virtual experience, thanks to the latest generation devices, becomes interactive and multisensory. The environments and scenarios recreated ad hoc react to inputs and events generated by the visitor/user, providing cues for interaction, fun and useful information for in-depth analysis of different types of situations and topics.

These are some of the reasons why Virtual Reality is the technology that has been for the project created for PafaSystem, a leading Italian company making machinery for fancy yarns and spinning preparation, which participated at ITMA 2019 with an ETT customized stand. The company introduced itself to the public through innovative Virtual Reality storytelling in five languages. Thanks to three all-round VR stations, visitors immersed themselves in the world of Pafa, discovering the company's history and getting a close-up view of the production process, right up to the finished machinery. The four top models of yarn production machines (Airjet, Legafil, Rocfil, Fancy Frame) may be examined thanks to videos and 3D reconstructions.

Virtual Reality, in fact, enables users to experiment a simulated reality, allowing them to make experiences in a digital environment. The advancement of technologies allows, through devices such as VR or Cardboard viewers, to navigate in photorealistic environments in real time, interacting with the objects present in them, in this case yarn production machines.

For each specific project, ETT is able to cover the whole "chain", from the initial concept to the final technical realization. The company, in fact, deals with the development of the software, the contents and the engineering of the solution for the creation of a complete project, identifying the best solutions, up to the use of the most relevant device, calibrating the choice according to the context, the customer's needs, the fruition and the final content.

Just as in the case of the Pafasystem project where users can experience the VR technology through special viewers and 3D video-reconstructions, which, together, make up a fascinating and engaging immersive storytelling. The ability to manage and coordinate the entire process, starting with the design, allows ETT to follow and complete the exhibition design and visitor experience.

3.6 AR Quality Check for Automotive Production, a Mobile App that Easily and Intuitively Supports the Industrial Production Process

ETT has developed for the automotive production an Augmented Reality based application dedicated to checking, monitoring and verification of any imperfections in automotive production. A camera pointing at the engine recognizes a possible defect and associates it with the corresponding 3D model. By viewing the engine in Augmented Reality and clicking on a predefined point of the 3D model, a detailed data sheet shows possible failures or related problems. On a dedicated tablet, operations can point to the engine and a 3D reconstruction appears showing components with detailed data sheet and photos of suspicious defects.

The continuous and proactive search for innovative solutions has facilitated the maturation of new knowledge and skills with high added value that, as demonstrated by the project carried out for the automotive production by ETT, has allowed the development of cutting-edge solutions to support the sector, in this case automotive, with the creation of innovative solutions that, through the use of Augmented Reality, allow the identification of possible errors and potential defects during the production process, with considerable advantages in terms of efficiency and quality.

As this project demonstrates, Augmented Reality can be a useful design tool, because it is able to generate dynamic and interactive representations, exploiting affordable technologies. As for this project realized for the automotive production, every AR experience takes place in a real environment, in this case, that of automotive production (Fig. 4). By definition, the key of the AR experience lies in enriching the real world with virtual information, better if of a certain usefulness, as it happened in this case study, where the AR content allows to obtain valuable information to reduce the risk of errors or even simple imperfections during the automotive production phase.

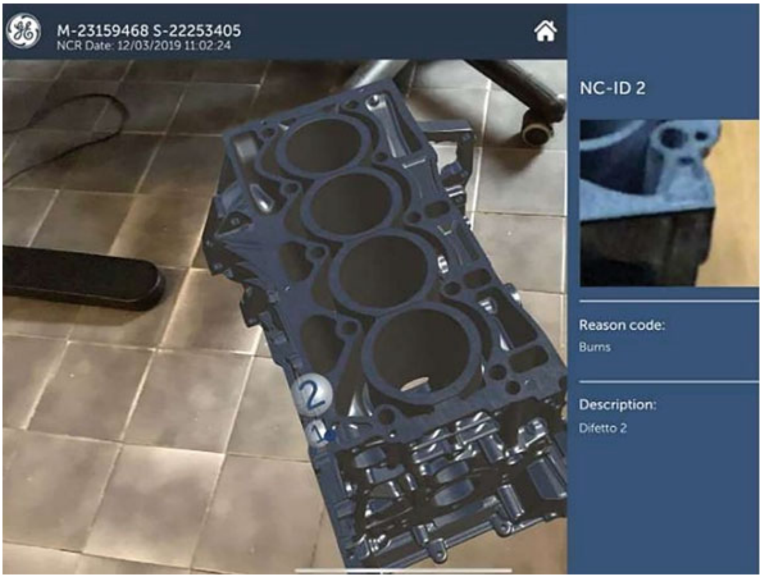

Fig. 4 The AR engine visualization app created for the automotive production

3.7 NIA VR, Realistic Simulations Supporting Training and Fire Prevention

For the Fire Investigation Structure (NIA), ETT has created an innovative tool able to increase the ability to collect information on the intervention scenario, in order to facilitate fire investigation activities, introducing advanced technological tools that could be further expanded in the future. The NIA-VR app is an example of immersive technology applied to high quality training and operational support of personnel operating in critical intervention scenarios (Fig. 5).

Applying the HTC Vive technology, through the custom made app, it is possible to create realistic simulations to support the investigative activities. The application allows to analyze, through simulations based on planimetric surveys, 3D data and photographic surveys as well as various types of issues related to the inspection activity for the search of the causes of fires and explosions.

The activities in VR environment are performed by a viewer and a pair of hand related controllers (HTC Vive) managed by a software developed by ETT. The user has a wide variety of tools to perimeter the area to be inspected, detect the signs of thermal damage on structures and materials, simulate sampling, carry out a search for accelerants, performing a contextual photographic survey to represent the state of the places observed, document the finding activities and fire signs found (Fig. 6). Once the VR inspection of the various environments affected by the fire has been completed, the application allows to represent areas with different levels of damage in order to identify the possible dynamics of the fire and trace the location of the area of origin of the event. The activity in VR environment prepares the fire brigade personnel to better interpret the signs of thermal damage left by fire inside a real physical environment subject to inspection.

Fig. 5 A training session taking place in the NIA VR environment

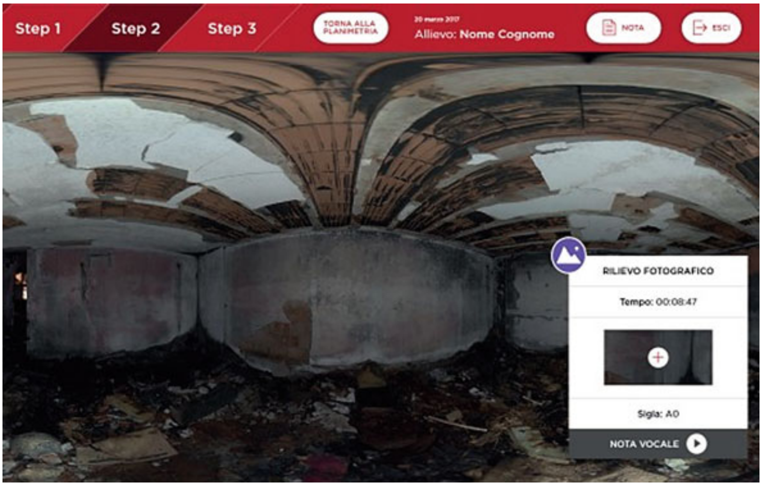

Fig. 6 The VR environment layout created for the NIA project

Therefore, ETT has created a unique app in the Italian panorama of Public Administration, which allows the Fire Brigade Squad Chief to collect multimedia documentation related to personnel training. The information collected is uploaded into the Operations Room system directly from the app. In 2017, NIA VR has been awarded with the “$10 \times 10 = 100$ Projects to change the PA” award, convened by ForumPA, as one of the most innovative projects of the year.

3.8 Electric Vespa, a New Showcase Giving a Fresh Look to Sales Outlets and Vespa Visitor Centres

ETT has created an exhibition proposal for Electric Vespa inclusive of many solutions, technologies and concepts: silence, coolness, connection, customization, user-friendliness. The project has been declined in function of numerous exhibition spaces.

In order to enhance the unmistakable aesthetics of the Vespa, a system of LED strips enhances the exhibition space. Light flows like water through the strips, taking on the colouring of Electric Vespa trims (Fig. 7). When starting to move, the software records roller movement and intensifies the light on the podium. The trail of light goes through the vertical elements and illuminates the whole area, creating a discreet but effective lighting choreography and maximizing the emotional impact of Italy’s most famous and loved scooter.

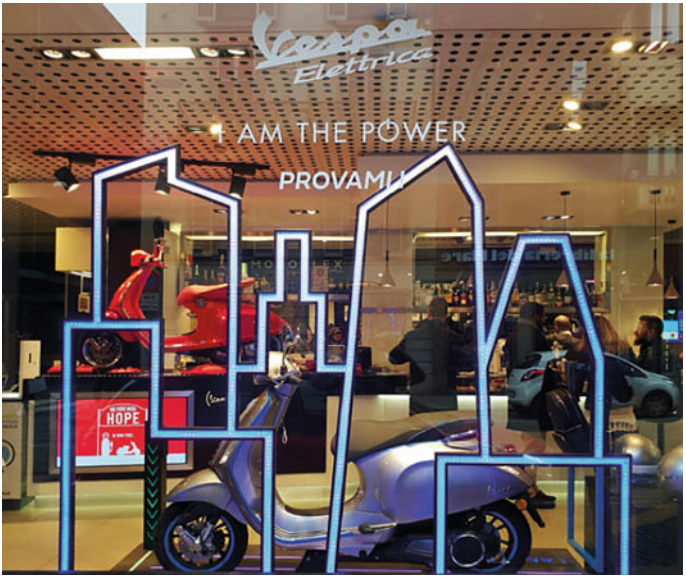

Fig. 7 The lights set-up created for Piaggio

The project, created by ETT for Piaggio, dialogues with users, stimulating the senses of those who visit the exhibition, creating a very fascinating overall choreography: a luminous landscape built around the iconic Vespa, displayed in its electric version, which, thanks to an original and innovative design, is enhanced in its proverbial beauty and material quality.

The project has been designed to enhance one of the most successful products of Italy which, despite the many versions produced, remains one of the most popular and desired Italian brands in the world, for which ETT skilfully used the best lighting solutions on the market, transforming the Vespa into an example of postmodern aesthetics.

3.9 Vodafone Data Center, Discover the Vodafone Data Center Together with a Virtual Guide

In a global context that sees a growing number of companies choosing VR to present their products to the public, ETT has carried out project for the multinational telecommunications company Vodafone, setting up an immersive, engaging and emotional experience in which user can interact with a virtual guide. The storytelling project aims to create a virtual visit to the Vodafone Data Center. Just wearing the headset, users are ready go on a virtual journey of the Vodafone Centre, along with a Virtual Character.

By looking at the 3D map and selecting one of the points of interest, the character will guide users and help them to discover the various features and peculiarities of the space. Some infographics are also available to learn more. Thanks to Virtual Reality new narrative levels overlap with reality and allow the user to live an immersive, engaging and above all interactive experience thanks to the virtual guide that reveals the secrets of the Vodafone Centre.

With this project realized for an important client like Vodafone, ETT wanted to arouse amazement and interest in the end user, exploiting the potential of Virtual Reality, which is a complex technology in terms of design but very fascinating. The project is based on the will to develop complete solutions without neglecting any aspect, starting from the needs expressed by the client, but also taking into account the users' point of view and their expectations regarding the experience that awaits him, the technology they will use and the way they will interact with the space in which the exhibit will be allocated.

3.9.1 Vicalvi Contract Showroom

The exhibition spaces shaped on linear physical models propose an itinerary between the fragments and the negative space, i.e. the alternation of pauses, which rhythms them and separates. Technology, instead, has the power to transform them into performing spaces dominated by the associative logic of hypertext in which the user is enabled by interaction to an active role. This is the approach at the base of the project conceived and realized for Vicalvi Contract.

The exhibition space was completely designed and built to host Vicalvi products at the Surface Design Show of London (Fig. 8). The company, producer of an innovative selection of floors, walls, bathroom and spa furniture, has entrusted ETT to the realization of a highly technological stand inside the fair, which would allow the public to interact with the innovative coating materials for floors and surfaces presented, deepening their origin and uses. Users just need to touch the material of interest to be able to read the details of the monitor and access to a slideshow dedicated to places in which it was used.

The touch screens are created and adapted with respect to the places of use: great importance is given to the aesthetic point of view of the screens, their insertion in the setting and the heights according to the different users, such as children and disabled people. These devices increase the ease of access to multimedia content and enhance usability.

Thanks to touch screens, the exploration of multimedia content (descriptions, images and videos) created by ETT for the Vicalvi Contract showroom is simple and intuitive or everyone. The workstations equipped with this type of monitor have wide possibilities of use, are simple to manage and create important information and learning points.

Fig. 8 The multimedia set-up created for Vicalvi contract showroom

4 Conclusions

As we have seen, at the heart of the technological revolution impacting the industrial sector, leading to the digitization of processes and innovation of business models, there are Augmented and Virtual Reality, technologies that, respectively, ensure the enrichment of reality and virtual simulation of scenarios, bringing many benefits to industrial activities, including increased productivity and employment, optimization of business processes and greater efficiency, safety and quality along the production process chain.

Specifically, it has emerged that these “immersive technologies” are increasingly able to play a decisive role in the sector in which they are used, offering the chance of being applied to different areas of production processes, making the boundary between the physical world and the simulated world less strict, thus creating a feeling of immersion and mixing elements from potentially different and heterogeneous contexts.

Wanting to condense in a general concept the discourse developed in this work, it can be said that it is possible to trace back immersive technologies to the wider set of the so-called “Industry 4.0”, to be understood as a very wide set of technological solutions, aimed at making the parts of the enterprise or industry more integrated and, by extension, to connect efficiently the production realities with the outside world. The analysis carried out in this work aims to identify some areas that are typically strategic for companies, in whose context immersive technologies can find applications: the case studies described show that AR and VR, when put at the service of companies, allow to actively involve users, putting them in a position to play a leading role in the experience, which often becomes multisensory. Moreover, innovative technologies such as AR and VR, increase engagement and interaction between users and objects “on display”.

In conclusion, as also expressed by the case studies we have dealt with, it is possible to affirm the importance of the contributions made by immersive technologies to marketing and communication strategies of companies, contexts in which the economic, competitive and technological changes determine a progressive change in companies’ communication processes towards their target audiences.

It follows that technologies such as AR and VR, have the possibility to introduce important innovations from the point of view of companies’ production and communication strategies.

Science Tour and Business Model Using Digital Twin-Based Augmented Reality

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Abstract The purpose of this study is to propose a theoretical framework for a digital twin-based smart science tourism system using augmented reality in Gwanghwamun Square. To date, smart tourism service was not sufficiently developed for the provision of relevant tourism information to visitors as tourism contents were managed by the separated information system of each institution. The tourists could not receive ideal tourism routes based on their preferences and also according to congestion of each institution. Moreover, the business model using existing tourism services was not well developed, and thus the current tourism services have not sufficiently contributed to the revitalization of the regional economy. We designed a digital twin-based tourism content management system that provides integrated management of tourism information, and augmented reality (AR) science tour services which are included with contents recommendation, best path finding, contents sharing and gamification. We also adopted a business model using the AR tourism platform based on digital twin technology which could contribute to the invigoration of the local economy.

Keywords Digital twin · Smart tourism · Augmented reality · Business model

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1 Introduction

There are various museums, art galleries, science museums, and experience centers in and around Gwanghwamun Square. In particular, Gwanghwamun Square and its surroundings are valued as a place to experience the history and latest trends of science in Korea. There are many cultural organizations with science heritage contents in Gwanghwamun Square such as the Gyeongbokgung Palace, National Palace Museum of Korea (traditional science), National Museum of Korean Contemporary History (industrial science), National Museum of Modern and Contemporary Art (media art), National Children's Science Center, and corporate technology experience centers (ICT).

As science heritage contents are managed by the separated information systems of each institution, they were not integrated well and therefore tourists have difficulty accessing desired contents. In order for tourists, who are visiting Gwanghwamun Square, to receive tourism services on a single platform, the contents management systems must be integrated. However, science heritage contents are saved and managed as their own metadata; therefore, there are limitations to integrating, managing, and utilizing them (Patel et al., 2005). Furthermore, the existing tourism information systems and applications could not recommend tourism routes based on the individual tourist's preferences and the congestion of each institution, thereby failing to support convenient and pleasant visitor experiences. Moreover, the existing tourism services have struggled to contribute to the revitalization of the regional economy due to lack of business models linking to existing tourism services (Smirnov et al., 2014).

We propose a digital twin tourism content management system with metadata that provides integrated management of tourism information around Gwanghwamun Square. This includes digital twin-based content and route recommendation system that could provide customized contents as well as an optimal route recommendation service. In addition, we propose a business model with the science tourism platform based on digital twin technology that contributes economic activities in Gwanghwamun Square by integrating various contents online.

In order to achieve the aim of this study, following objectives were set:

1. It proposes a digital twin-based tourism content management system to integrate, manage, and utilize tourism contents that are managed by separate information systems,
2. It proposes a digital twin-based tourism business model that resolves information asymmetry and maximizes customer satisfaction through economic efficiency and data utility.

If a digital twin-based smart tourism platform is successfully implemented, then it is expected that this will encourage tourists to revisit Gwanghwamun and also contribute to sustainable growth of local tourism-related businesses in Gwanghwamun Square.

2 Literature Review

The Gwanghwamun Square, a space imbued with symbolism, has been a hub of politics, economy, culture, and tourism in South Korea since the fourteenth century. There are many cultural resources and organizations in and around Gwanghwamun Square (Shin & Zoh, 2013). In particular, the Gwanghwamun Square is in the central location of science heritage experience, where the National Palace Museum of Korea (traditional science), National Museum of Korean Contemporary History (industrial science), National Museum of Modern and Contemporary Art (art and technology), and corporate technology experience centers (ICT) are located. The historical contents of Gwanghwamun are managed together with the history of Gyeongbokgung Palace, but historical and cultural science heritage contents are managed separately by different institutions, which makes it difficult for tourists to understand and experience their historical and cultural connections. In order to address this issue, there is a need for state-of-the-art digital twin technology which can provide integrated management of these scattered historical and cultural contents (Jouan & Hallot, 2019).

Digital twins model the physical world and systems with the same structure in the virtual world and enable monitoring, simulation, information visualization, service validation, and service participation in the relevant physical space using various sensing technologies provided by IoT and 5G (Seungyoub Ssin et al., 2018). The technology was initially developed by General Motors (GM) to conduct detailed checks of their products, but it is now receiving much attention in other industries due to its ability to solve various industrial and social problems. Digital twin technology was initially used as an information visualization system for simulation in the manufacturing industry (Zuehlke, 2010). This led to the emergence of smart factories, which upgraded their existing facilities by combining automation technology and IoT (Lucke et al., 2008). Managers can now efficiently monitor maintenance and repairs, machine control, safety management, and error handling while manufacturers are capable of rational distribution, production planning, and simulation (Wang et al., 2016). The successful experiences of smart factories have laid the foundation for the establishment of smart cities that apply technology combining IoT, 5G, Cloud, Robot, AI, and AR/VR—the core elements of the Fourth Industrial Revolution—to the regeneration of old cities and the construction of new ones (Chen et al., 2017). In the tourism context, the power of digital twin technology in integrated management and simulation could provide an alternative solution for successful management of scattered tourism resources in a single integrated system.

An existing integrated tourism service called 'Sejong Belt' promotes cultural organizations and visitor attractions nearby Gwanghwamun Square (Ha, 2011). This is a tourism service that connects 15 theatres, including Sejong Centre for the Performing Arts and Seoul Namsan Traditional Theatre; five museums, including Seoul History Museum and the Bank of Korea Money Museum; and five art museums, including the Seoul Museum of Art and Gallery Hyundai, around Gwanghwamun Square. This service offers customised products and services according to price, target, time, space, and theme through the Sejong Belt website and information Centre. However, this integrated tourism information system failed to provide customized service according to the preferences of individual tourists and also based on the congestion of each institution. Moreover, this service was developed from the perspective of suppliers and therefore it could not induce continuous participation of tourists. Digital twin-based tourism services enable tourists to receive continuous service by supporting authoring and sharing of tourists and recommending contents and optimized routes, based on consideration of individual preferences and congestion on a real-time basis.

Virtual reality is a technology that enables tourists to experience tourist destinations prior to their physical visit. Immersive contents based on virtual reality are widely used in the context of smart tourism (Lee et al., 2019). For example, Marriott hotels provide virtual tours of Rwanda and the Andes, to allow tourists to experience the surroundings. Augmented reality (AR) has the benefit of enriching experiences by enabling tourists to experience various media along with the tourist attractions on site, and many tourism contents using AR have been created. For example, in Korea in 2017, the KAIST Graduate School of Culture Technology UVR Lab developed the K-Culture Time Machine 1.0, a smart tour application to experience historic sites beyond time and space, using VR and AR (Kim, E. et al., 2016). This application connects to an external database to retrieve figures, places, events, and media related to historic sites based on ontology and provides such information to users. Moreover, it enables users to experience geo-spatial contents by restoring and reproducing lost cultural heritage sites and historical events. However, existing VR and AR tourism applications are not sufficiently developed for seamless service, as they are limited by the intentions of service providers which aim to merely deliver information. Furthermore, they do not provide convenient and beneficial tourism services such as real-time route information for tourists.

A business model is the basic framework governing how a company will do business, deliver value to customers, and generate profits. It is therefore used as a means to maintain competitiveness of the existing business, expand, and strategize new business. The US venture capital survey agency, CB Insight, revealed that the main cause of failure of start-ups was related to the business model (Nam, 2016). For example, Geevor Tin Mine Museum in England is the largest historic site related to mining in the UK and is located amid the dramatic landscape of the Atlantic Coast of Cornwall. Results of a survey on visitor experience of an integrated (VR&AR) environment showed the experience to have a crucial impact on revisits (Jung et al., 2016). However, the lack of pre- and post-marketing meant that the connection to the business model was somewhat inadequate. Linking the VR&AR experience with the business model will be more effective for pre- and post-experience marketing.

In conventional tourism, there is a close link between tourism products and consumers, and the growth of platform businesses along with technological development have brought the two into direct confrontation. A platform business in the tourism industry can be an 'integrator' like an online travel agency which delivers tourism products to consumers with an external platform business operator in the middle, or a 'two-sided' type like TripAdvisor or Yelp, with two main agents enhancing value by interacting on the platform (Lee et al., 2018). It is important to create value as a business platform through commissions and advertisements, but there is limited research on how to use the data effectively. For example, it may be more useful to study recommendation services based on user data, i.e. finding optimal tourism routes by analyzing the previous tour data.

Tate Modern, a world-renowned urban regeneration project which successfully combined art and business, reinvented an abandoned factory as an artistic space. It has become a major tourist spot in the UK which attracts countless tourists (British Council, 2020). Tate Online is more than just a website for the art gallery; it also includes an online catalogue of the entire Tate collection as well as webcasting of lectures and events. In addition, it features the 'Tate Papers', an online academic journal; carries out online-only activities or exhibitions; and communicates with visitors on social media (Facebook, Twitter, etc.) (Lee, 2017). However, it needs to expand the role of its platform business, since it holds free exhibitions and does not make profits from admission fees. Its online shop has many products but lacks publicity. It is necessary to induce customers to participate in online product development or nurture talented local artists by expanding online exhibitions.

To conclude, a digital twin based platform combining various technologies such as AR/VR, AI, 5G, and IoT will have huge social impacts and also economic impacts due to the potential of business models generated by this new platform.

3 Proposition of Digital-Twin Based Tourism Platform and Business Model

We propose a digital twin-based science tourism service to enable tourists obtain seamless tourism services via integrated management of scattered science heritage contents and authoring and sharing of tourists. The Data section in Fig. 1 includes data generated from the existing database as well as data generated by location shifts after tourists generate media on their mobile phones. The generated media and data are sent to the data platform. In the Data Platform section, the collected tourism data is integrated and saved in the form of predefined metadata, and it enables numerical simulation to visualize data tables and predict tourism figures (e.g. congestion, tourism demand, movement information) in terms of data management. The Digital Twin section supports monitoring (e.g. determining the location of children in tourist sites), visualization of tourism data (e.g. floating population on a 3D map), tourism planning (e.g. finding optimal travel routes), simulation (e.g. predicting traffic jams), verification of real-time tourism information, and operation of tourism facilities.

Next, the AR Tour Platform section supports technology to provide precise location-based services and in-situ authoring, 2D/3D rendering of tourism information, context awareness to provide service that reflects user and environment data, and user interface support. AR services include recommendations of tourist spots for individual tastes related to science, finding the best routes to enjoy tours from a current location, tourism and authored data sharing with tourists nearby, and game services.

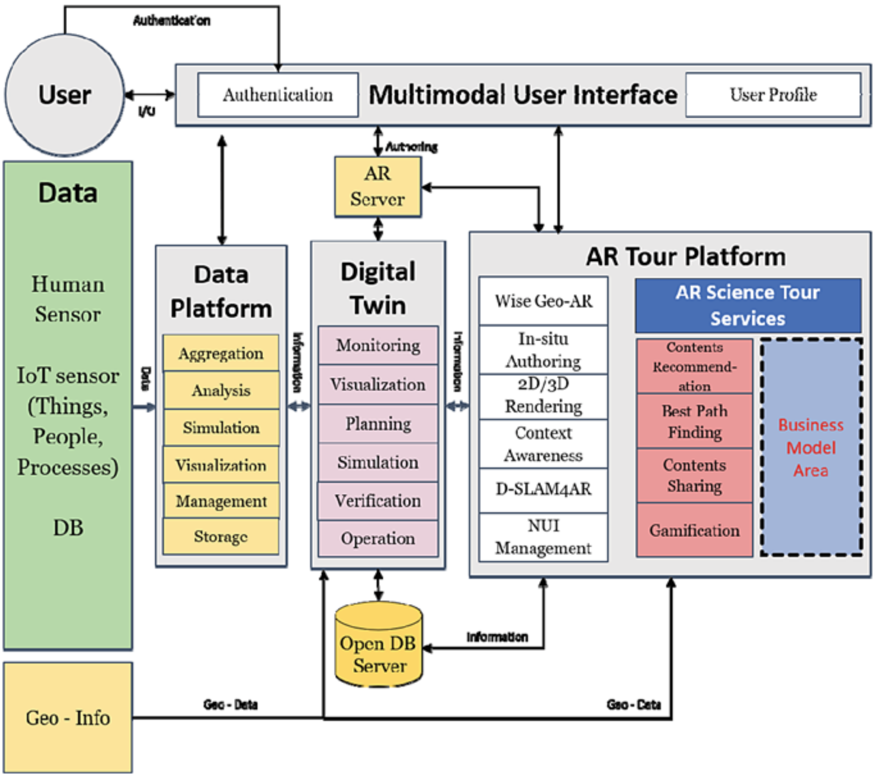

Fig. 1 Concept map of digital twin-based AR Science Tourism Service

Finally, tourists undergo the authentication process through multimodal interfaces such as smartphones and AR glasses to experience digital twin-based services suited to user information. Moreover, they create location-based contents and upload and share them on digital twins through the AR server. Tourist site managers can provide optimal services for tourists through various simulations on the data platform and digital twin.

In the concept map of the digital twin-based AR tourism service in Fig. 1, the data platform obtains data from the mobile devices of tourists, IoT sensors installed at tourist sites, and databases of cultural organizations, and then integrates, analyses, simulates, visualizes, manages, and saves the data. The digital twin collects information from the data platform and uses it for monitoring, visualization, planning, simulation, verification and operation. The AR platform prompts the AR server and open database server to provide AR/VR tour services through Wise Geo-AR, in-situ authoring, 2D/3D rendering, context-awareness, D-SLAM4AR, and NUI management. Tourists can receive services such as science heritage content recommendation, pathfinding, science heritage content sharing, and science heritage contents gamification.

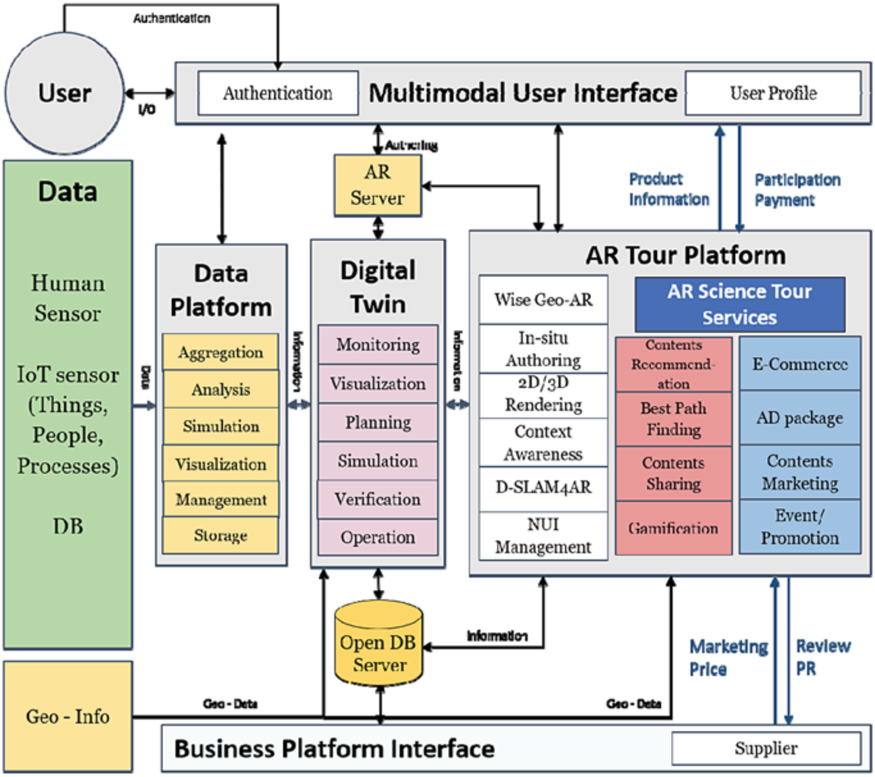

Fig. 2 Digital twin-based scientific tourism business model

The content sharing feature of AR Science Tour Services can resolve the digital divide among regions through immersive experiences of science tourism by supporting digital visualization technology online. Moreover, by combining and providing various tourism contents using features such as content recommendation and best path finding, the platform will increase tourist satisfaction and accessibility of relatively isolated tourist sites, thereby promoting economic activities in the surrounding areas. Finally, AR gamification with in-situ learning combined with location-based services induces an increase in the flow of content understanding through rewards and experiences to produce a scientific tourism business model (Fig. 2).

The digital twin-based tourism business platform provides products and information that meet the needs of visitors based on big data analysis of tourist's behavior in connection with the AR Tourism Service. As a result of testing the AR tourism platform through Dublin tourists, the user's interface design, easy navigation, and program speed were important (Han et al., 2013). Both large and SMEs (small and medium-sized enterprises) which provide tourism products or services can secure channels to promote and sell their products through the digital twin-based tourism business platform, while they are holding sales promotions to sell tourism products. Moreover, they can establish a business ecosystem by analyzing data from customer reviews and providing feedback to businesses, as well as obtaining new customers by increasing customer touchpoints in connection with the external social media platform. This can contribute to the revitalization of the regional economy by increasing tourist satisfaction and offering quality information on products and services according to individual preference (Yu, 2017).

By applying the technology and business model described above, tourists can experience virtual artifacts in Gwanghwamun Square and recommend semantically related content through digital twin-based AR. The tourists decide the artifacts of interest through the AR experience, and the Digital Twin recommends the AR tourism route in consideration of the visitor's preferences and the congestion of cultural institutions. The tourists can watch virtual and real artifacts and upload their experiences to digital twins as well as share them on SNS. Digital Twins store and manage the tourist experience information and reuse it for content recommendations when they are returning. The tourists can access the digital twin through virtual reality to purchase tourist products based on the objects of interest after the tours.

4 Discussion and Conclusion

The digital twin-based smart tourism content management system provides customized services for consumers using metadata based on existing tourism resources. Customized contents and optimal route recommendation services even induce tourists to visit tourist attractions that had been relatively neglected due to the lack of information. Therefore, the newly proposed system would result in the balanced development of the regional economy and a ripple effect on the growth of tourism-related businesses. Furthermore, it also provides a high-quality business platform with increased tourist satisfaction by inducing understanding of contents and flow through rewards and experience.

We expect that it proposed a framework for digital twin-based AR science tourism services, which will contribute to the development of data management and utilization methods by using a metadata-based digital twin to integrate various contents. Besides, this study contributes to inducing revisits of tourists and revitalizing the regional economy by proposing an AR science tourism platform business model.

This study proposed a digital twin platform structure and content and path recommendation services based on this platform from the perspective of content managers of digital twin-based tourism services. Academically the study stimulates a discussion on the potential benefits and challenges of the new digital twin-based tourism service platform from the perspective's technical development as well as a business model in the context of science heritage tourism. Further research is required on user experience and VR/AR application interfaces from the perspective of tourists. Furthermore, we anticipate quantitative research and validity analysis on the suitability of the business model for digital twin-based science tourism services.

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A Matter of Perception Investigating the Effect of Virtual Reality on Spatial Understanding

Kristina Krinizki, Marnix S. van Gisbergen, Shima Rezaei Rashnoodi, and Tim van der Grinten

Abstract Within the industry of architecture, interior design and construction, stakeholders and clients can differ significantly in their level of spatial understanding. Traditional media and new media, such as Virtual Reality (VR), are used to visualize spaces to create a bridge between professionals and non-professionals in the understanding of space. However, it remains unclear which medium increases spatial understanding for non-professionals more effectively. In this study we compared spatial understanding among non-professionals of a real space, an apartment, using three conditions: (a) being in the real space, (b) being in VR and (c) through a traditional desktop screen. Forty-five participants estimated spatial measures such as height, length and depth of a room and its furniture (objective spatial understanding). The results revealed that objective spatial understanding did not differ significantly between the three conditions. However, non-professionals revealed that VR made it easier to estimate the measurements of complex and less familiar objects and made them feel more confident about the accuracy of the estimated measures. The feeling of engagement was found to be a possible predictor for this effect. In addition the possibility to make use of one's own body as a reference point in VR, increased confidence as well. The results indicate that VR may improve the communication between clients and architects and interior designers, but only when it concerns complicated spaces and unfamiliar objects.

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Keywords Virtual reality · Spatial perception · Architecture · Experience

1 Introduction

Within interior design and architecture, spatial perception plays a crucial role in communication between stakeholders. To convey the information required for understanding the proposed design of a space to the client, experts communicate through different media (Van der Land, Schouten, Feldberg, van den Hooff, & Huysman, 2013). However, this is a challenge as the level of spatial understanding between expert and client often differs significantly, and visualizations might not be understood accurately by clients (Bouchlaghem et al., 2005). Spatial understanding is defined by Sun et al. (2014) as the ability to understand the shape, size, location, and texture of an object or space. Whereas untrained minds have to use several cues and think carefully to understand visualizations of architectural designs, experts understand these visualizations more easily and are able to translate them from the physical world into the virtual 2D and 3D world (Houck et al., 2013; Jiang, 2014). This phenomenon is called spatial abstraction gap (Mullins, 2006). To bridge this gap, architects translate their concepts from expert language into a more intuitive visualization language (Lubell, 2016). To do this, several media are available: traditional drawings, 2D paper plans, moodboards, physical models, 3D screen-based models and animations. Created with advanced modelling software such as Rhino, AutoCAD or SketchUp, digital 3D models of proposed spatial designs are still mostly displayed on two-dimensional desktop screens. This requires clients to translate the screen-based model into a mental 3D object, which can be a demanding task for untrained persons (Zhang et al., 2012; Houtkamp, 2012). However, since 2016 affordable high-level Virtual Reality (VR) has been added to this pallet (van Gisbergen, 2016). VR is perceived as a promising and effective medium for architect-client communication (e.g., Halsy, 2016; Martín, 2016; Mottle, 2016; Portman et al., 2015; Viet et al., 2009). Even in a more effective way compared to other media (Holth & Schnabel, 2016). The capability of creating highly realistic and intuitive experiences sets VR apart from traditional visualization media, which may have a high risk of being too abstract (Keskey, 2016). Previous research has shown that VR has the capacity to elicit the feeling of being in mediated virtual spaces (e.g., Lee, 2004; van Gisbergen, 2016). If VR can make clients feel present in the virtual space, it could help them understand the proposed spatial design (Hofmann, 2002).

According to van Gisbergen (2016), the technology used in VR incorporates the following four dimensions: (I) sensory, (II) interaction, (III) control, and (IV) location. Each dimension helps to explain why VR could have a benefit on spatial understanding over other media. For instance, VR might outperform desktop screens on the sensory dimension, as it provides the user with a natural eye-height, stereoscopy, and a large Field of View (FOV), thereby increasing perceived realism and enhancing the sense of presence in the virtual space (Houtkamp, 2012; Van den Boom, Stupar-Rutenfrans, Bastiaens, & van Gisbergen, 2015). Within the interaction and control dimension, which makes use of technologies that enable exploration and navigation in the virtual space, VR might outperform desktop screens because in VR users can move and behave more naturally (Kuliga, Trash, Dalton, & Hölscher, 2015). They can kneel or walk around objects, imitating real-life behaviour, which enhances the understanding of virtual spaces (Usoh et al., 1999; Jiang, 2014; Houtkamp, 2012). Also, VR allows for better location tracking, which enhances the sense of presence more as compared to desktop screens (Slater & Steed, 2000). However, previous research does not offer a consistent picture of the effect of different visualization media on spatial understanding. Some studies have shown that screen-based visualization media can facilitate spatial understanding equally well as VR media (e.g., Schnabel & Kvan, 2003; Westerdahl et al., 2006) or showed problems with VR and space estimation (Sahm, Creem-Regehr, Thompson, & Willemsen, 2005; Interrante, Ries, & Anderson, 2006). However, other researchers demonstrate the importance of immersive VR media for supporting the spatial perception of virtual spaces (e.g., Fröst & Warren, 2000). Previous studies employed a variety of different visualization media and different spatial tasks to assess spatial perception in virtual space, making it challenging to draw unambiguous conclusions. As yet no study has compared the effects of the commonly employed desktop-based visualization with the increasingly important high-end head-mounted VR devices and tested the impact of presence on spatial understanding within these media.

2 Study

In this study, two different types of digital visualization media were compared on spatial understanding. We compared a real environment that was displayed within a traditional computer desktop screen and within a high-end head-mounted Virtual Reality device. We measured ‘*objective perception*’, spatial parameters that can be assessed by accuracy measures, and ‘*perceived spatial understanding*’, the impression of understanding a virtual space. After receiving the briefing and signing the consent form (2 min), all participants were required to perform the *Mental Rotation Test* to assess individual spatial ability prior to the experiment (5 min). Participants were randomly assigned to experience an apartment through one of the following conditions; (a) being in a physical replication of the real space, (b) being in VR and (c) through a traditional desktop screen. Participants within the physical and VR space, were allowed to navigate or walk around the furniture from different perspectives, for instance, by kneeling or bending sideways. In the physical replication condition, participants were given one to two minutes to familiarize themselves with the furniture and the items in the space, and directly after, they were asked to estimate the size. In the mediated conditions, participants were either seated in front of the laptop or used the head-mounted VR device, and given two minutes to get used to the devices and space. Afterwards, they were asked to report the size estimations of the furniture items and room dimensions. Additionally, perceived spatial understanding was measured by self-report in all three conditions. The participants in the media conditions were then asked to fill out a questionnaire.

Participants. Visitors of a virtual reality centre were asked to contribute to the study, to ensure interest and previous experience with VR and reduce the newness factor (van Gisbergen, 2016). Forty five participants aged from 18 to 54 years (M = 24, SD = 7.72) reported normal or corrected-to-normal vision. Only seven of the participants can be seen as visual space experts (e.g., engineers, architects, or 3D artists), and were equally distributed over the three conditions.

Materials. An identical virtual environment was created for all three conditions consisting out of a loft apartment without any floor or wall coverings fitted out with a table, two chairs, a bench, a kitchen unit, and a floor lamp. The virtual loft represents a 3D visualization (created in SketchUp and running in Unreal Engine 4) of real lofts located at Strijp-S in Eindhoven. The room height of the loft is 5.08 m, and the length is 6.55 m. The sizes of the furniture items displayed in the virtual environments correspond with their real counterparts. Only the height of the floor lamp was scaled down from 1.77 m in the physical condition to 1.59 m in the virtual space. The degree of distraction within the virtual loft has been kept as low as possible in order to exclude possible influential side-factors. Patterns or tiles on walls or the floor could have been used as additional references when making size estimations, and therefore have been removed. In the HMD VR condition, participants wore the HTC Vive with a resolution of 2160 by 1200 for both eyes (1080 × 1200 per eye). As there was no possibility of interaction, no controllers were given to participants. They could explore the environment by walking in the designated tracking area. In the Desktop condition, participants sat in front of a 13 in. Asus ZenBook UX305CA laptop with a resolution of 3200 by 1800 pixels. Free navigation through the loft was possible by using the keyboard and a wireless Rapoo mouse (Fig. 1).

Measures. *Spatial Ability* was measured using 12 items from the Mental Rotation Test from Peters et al. (1995), that is based on the Mental Rotation Test from Vandenberg and Kruse (1978). The test is often used to measure spatial ability (e.g., Katsioloudis & Jovanovic, 2014). The test consists of items that represents a set of five two-dimensional drawings of three-dimensional geometric figures. On the left end of each item the target figure is given, followed by two rotated versions of the target

Fig. 1 Representation of the loft apartment in VR and desktop and a participant wearing the VR headset while looking at the virtual table

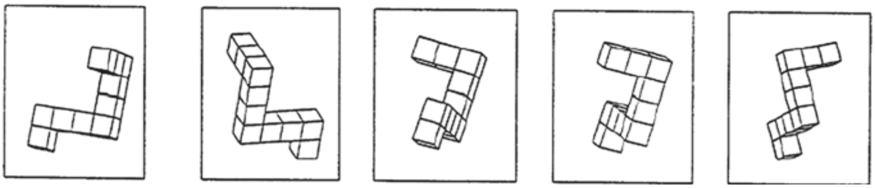

Fig. 2 Exemplary item in the Mental Rotation Test-A by Peters et al. (1995)

figure and two distractors. The participant is asked to choose which of the four drawings represent the two rotated versions of the target figure. The three groups did not differ in spatial ability ($F(2, 42) = 0.097$, $p = 0.908$). The spatial ability of all groups was average (an approximate score of 6 out of a maximum score of 15). Experts scores higher on spatial ability $M_{experts} = 11$, $M_{non\text{-}experts} = 5.4$, $t = 4.261$, $p = 0.00$) (Fig. 2).

Size estimations were measured by asking participants to mention their estimations of depth, height, and length of the furniture items as well as room measures in meters and centimetres (as in Geuss et al., 2010; Sun et al., 2014; von Castell et al., 2014). No time limit was given (cf. Loomis et al., 2003). Ease of estimation was constructed by asking the participants to evaluate how easy or difficult they perceived the estimation, and how confident they were in making the estimation, using 5-point semantic differential scales (e.g., 'difficulty' versus 'easy' and 'insecure' versus 'confident'). Level of difficulty and level of confidence were combined into one variable describing perceived spatial understanding called 'ease of estimation'. Moreover, the overall impression was measured by means of the question: "Please rate how well the medium could convey a good impression of the spatial dimensions" (1 = very bad; 10 = very good). Sense of Presence was measured using twenty-nine items of the ITC-SOPI scale (Lessiter et al., 2001) that consists of four factors: perceived naturalness, engagement, spatial presence and negative effects. Answers were given on a 5-point Likert scale (1 = strongly disagree to 5 = strongly agree). Perceived Usability was measured using nine items from the Usability Engagement Scale (5-point Likert scale: 1 = strongly disagree to 5 = strongly agree) from O'Brien and Toms (2010). Item statements ranged from "I found the medium confusing to use" to "I felt frustrated while trying to estimate sizes in the displayed environment".

3 Results

The results showed no differences *in MRT* between the groups, demonstrating an equal capability of spatial understanding (Mphysical = 6.3, Mvr = 6.1, Mdesktop = 6.7, $F(2, 42) = 0.097$, $p = 0.908$). Experts (M = 11) showed a better spatial understanding compared to non-experts (M = 5.5).

Size estimation was equal within VR and Desktop (Mphysical = 1.1, Mvr = 1.1, Mdesktop = 1.1, $F(2, 42) = 0.414$, $p > 0.05$). Moreover, the mean scores of accuracy indicate a general overestimation of size in all conditions. Each furniture item showed approximately the same result. For all items, overestimation never exceeded a value of twenty-nine per cent. The maximum underestimation (chair depth estimation mean in desktop Desktop) was 7.1%. Especially length of the table (M = 1.063, SD = 0.215) and depth of the chair (M = 0.981, SD = 0.247) have been estimated fairly accurate in all conditions. Room dimensions were only estimated in the VR and Desktop groups. In general, both room measures were estimated accurately in both of the media conditions. However the results indicated that overestimation was higher in Desktop (8%) compared to VR (7.7%) ($t(28) = 2.232$, $p = 0.034$).

Data analysis revealed that only in two out of eight measures (floor lamp height and room length), *perceived spatial understanding* differed between VR and Desktop. A post hoc test revealed that in Desktop participants perceived the floor lamp height as more difficult to estimate and were less confident about their estimation than participants in the real world condition ($p = 0.001$) and in VR ($p = 0.008$). In VR participants also felt more confident and perceived the estimation as less difficult. Moreover, in VR all rooms were perceived equal in level of difficulty and confidence, whereas using desktop participants found it harder to estimate the length of the room than its height. Overall estimation impression did not differ significantly ($p = 0.40$) between VR (M = 6.6, SD = 1.12) and Desktop (M = 6.1, SD = 1.85) (Table 1).

Table 1 Pearson correlation between perceived usability, novelty, mean accuracy, ease of estimation and overall grade

		Perceived usability	Novelty	Accuracy	Ease of estimation	Grade
Perceived usability	Pearson	1	−0.569	0.288	−0.614	−0.622
	P		**0.001**	0.123	**0.000**	**0.000**
	N	30	30	30	30	30
Novelty	Pearson	−0.569	1	−0.472	0.6	0.568
	P	**0.001**		**0.008**	**0.000**	**0.001**
	N	30	30	30	30	30
Accuracy	Pearson	0.288	−0.472	1	−0.047	−0.195
	P	0.123	**0.008**		0.758	0.199
	N	30	30	45	45	45
Ease of estimation	Pearson	−0.614	0.6	−0.047	1	0.636
	P	**0.000**	**0.000**	0.758		**0.000**
	N	30	30	45	45	45
Overall grade	Pearson	−0.622	0.568	−0.195	0.636	1
	P	**0.000**	**0.001**	0.199	**0.000**	
	N	30	30	45	45	45

P values in bold represent the significant values below 0.05

As expected, the experience of spatial *presence* (t (28) = 6.025, $p = 0.00$) and *engagement* (t (28) = 3.918, $p = 0.001$) was stronger for VR ($M_{presence} = 3.6$, $M_{engagement} = 3.9$) compared to Desktop ($M_{presence} = 2.3$, $M_{engagement} = 2.9$). Engagement showed a significant correlation with the level of difficulty and confidence of the size estimations ($r = 0.430$, $p = 0.018$). The results indicated that the predictor engagement explained 18.5% of the variance ($R2 = 0.185$, $F(1, 28) = 6.349$, $p = 0.018$). The higher the engagement, the higher the ease of estimation ($B = 0.302$, $t = 2.52$, $p = 0.018$). No correlation was found between sense of presence and objective spatial understanding (spatial presence $r = -0.114$, $p = 0.456$; engagement $r = -0.155$, $p = 0.414$). *Perceived usability* did not differ between VR and Desktop (t (28) = -1.082, $p = 0.289$). However, in VR participants were more likely to continue exploring the furniture and room out of *curiosity* than in Desktop (t (28) = 2.503, $p = 0.018$). Perceived usability and novelty correlate with spatial understanding. Perceived usability explained 37.6% of the variance of ease of estimation ($R2 = 0.376$, $F(1, 28) = 16.902$, $p = 0.00$). It was found that the better perceived usability was rated, the higher the ease of estimation ($B = -0.453$, $t = -4.111$, $p = 0.00$; perceived usability reversed scoring). Novelty explains 36% of variance of the overall grade ($R2 = 0.360$, $F(1, 28) = 15.763$, $p = 0.000$). The higher novelty, the higher the overall grade ($B = 0.431$, $t = 3.97$, $p = 0.000$). Novelty also serves as a predictor for objective spatial understanding, explaining 22.3% of variance ($R2 = 0.223$, $F(1, 28) = 8.026$, $p = 0.008$). With $B = -0.089$, $t = -2.833$, $p = 0.008$, novelty negatively affects objective spatial understanding.

4 Conclusion

Contrary to previous studies, VR did not lead to a better objective spatial perception compared to Desktop and was not seen as more similar to real life. In fact, VR and Desktop both could be used effectively to estimate space. The research showed that novelty effects could have negatively influenced objective spatial understanding in VR. It can, therefore, be assumed that with increasing familiarity with VR media, objective spatial understanding in VR could be promoted and may outperform Desktop in the coming years. In all three conditions, size estimations were fairly accurate, which contradicts the common experience of professionals that clients have difficulties with spatial understanding of visualizations. Also, these findings contradict previous research. Studies exploring the spatial perception of virtual spaces, for example by assessing distance estimations through blind-walking tasks (Murgia & Sharkey, 2009; Ziemer et al., 2009), have reported a strong tendency of underestimation. However, the comparability between studies focused on spatial perception is impaired by the variation of media, spatial tasks, and measurements. Our study was the first to use familiar target objects, such as the table and chairs, and compare task performance between participants in HMD VR and Desktop directly. Because in our study the room, as well as the items, were fairly simple and very familiar (chair and table), participants probably rated the ability of both visualization media and the real world to be equally useful for conveying an accurate impression of sizes. The finding supported the idea that VR might have added value for less familiar and more complicated objects. VR was considered better and easier for sophisticated measures such as the height of an unfamiliar floor lamp or the length of the room. A possible reason for why VR worked better was the interaction dimension: only in VR participants could use their own body as a reference for estimating the lamp height. VR did also increase feelings of engagement and presence, although this did not always lead to better estimations. However, we do not know whether this might have an effect on the estimation of how the room "feels" (subjective space estimations), especially as an increase in engagement did not improve the ease of estimation. Considering the fact that VR and the real world condition achieved similar ratings for perceived spatial understanding, the general positive effect of VR, which is the predominant attitude in the industry at the moment, can be confirmed. To investigate the impact of VR on spatial understanding, we have started a project "Being There", in which for the first time we will mix computer-generated VR with 360 recorded spaces. In addition, we measure the effect of VR spatial understanding for unfamiliar rooms and living context related to temporary homes (for immigrant women), not only for non-professionals but also for professionals in training. Besides, we will create rooms that are not static but show changes and interactions as well as having more unfamiliar objects in the rooms. Both studies together will likely provide a better overview of the potential of VR in the understanding of space. Therefore, a more comprehensive understanding of space could be measured that takes into consideration both objective and subjective space estimations.

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Immersive Technology in Tourism and Theme Parks

Natureza Virtual: Enhancing Ecosystem Awareness by Using Virtual Reality in Educational Tourism

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Abstract Virtual Reality (VR) has been applied in several business scenarios. The tourism industry is one of the sectors that have great potential to take advantage of VR technology. Especially the marketing strategy and the tourism-travel which has tremendous opportunities in recent studies in Technology Acceptance Model (TAM), Self-Determination Theory in combination with Virtual Learning Environment (VLE). However, few attempts have been made in Educational Tourism to examine the factors that enhance the visitor experience by using new methods of the trending technology regarding VR interactive application in combination with Augmented Virtuality (AV). This research aims to better understand the elements that can influence the flow-state and presence of the participants in the VR experience based on studies and how educational tourism and the industry can benefit from the trending technology. We cover the VR App development focused on the educational travel for the touristic region of the International Biological Station of Duero-Douro and its consideration to the visitors of the Bragança Ciência Viva Science Center (Centro Ciência Viva de Bragança—CCVB). Although the research is still under development we aim to analyze the impact on the attitude of the visitors towards the destination of the cross-border region between Portugal and Spain, and the validation of the facts related to theories addressed in this paper.

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1 Introduction

Virtual Reality (VR) has been used in several immersive experiences with a wide range of uses in tourism, whether it's in the context of marketing, education, cultural heritage, or sustainability (Yung & Khoo-Lattimore, 2019). The educational tourism sector can greatly benefit from its potential during stimulation phases (Blecker et al., 2005). By joining VR 360 Video with Augmented Virtuality (AV) interaction (Alaae et al., 2018), the Marketing Strategy (MS) can also have a substantial influence on the information search process and the decision-making of potential tourists.

For this reason, immersion with 360 videos combined with interactive 3D models can be used as a way of describing a better consumers' involvement (Sheridan, 1992). This involvement allows tourists to create a more detailed and realistic expectation of their visiting destination, by enabling the feeling that they are in the real place. When succeeding in controlling and interacting with 3D objects, tourists can "feel" the Virtual Environment (VE) and develop an emotional connection (Tourism Australia, 2013; Wook et al., 2018).

VR technology offers a singular and interactive way for the dissemination of information that has previously been impossible (Yung & Khoo-Lattimore, 2019). As a result, VR is transforming the process of learning due to the experiences that cannot be obtained in any other way of formal education (Pantelidis, 2009). The assimilation of the material by using Virtual Learning Environment (VLE) context (Pan et al., 2006) among 360 videos and interactive 3D models also can improve the users learning curve through enjoyment and emotional connection (Tourism Australia, 2013). Educational tourism (ET) is known to be a facilitating method for teaching purposes since it creates involvement between the user with the physical, geographic and ecological environments (Scemin, 2012). Furthermore, the adaptation of VR applied in ET can lead to improving the knowledge construction, since the ability to simulate scenarios and the interactivity in a VE bodes with the current push towards e-learning (Mikropoulos & Strouboulis, 2004).

The main goal of this study is to understand the elements that may influence the users' flow-state, the presence factors when having a VR experience, and how the VR technology can better influence the ecotourism industry. The project consists of the development of the VR application "Douro Ecological-VR" to be part of the main exhibit of the Ciência Viva Science Center (CCVB), as a virtual interactive tour to Douro's river cruise, hosted by the International Biological Station (EBI).

The project aims to capture the entertainment nature of 360 3D Videos with other 3D interactive-virtual objects by extending the TAM to incorporate psychological elements of self-determination theory. That is, to understand consumer experience, the experiential MS, and to enhance ecosystem issues awareness.

The paper is organized as follows. After the introduction section, the literature review is presented in Sect. 2 describing the current digital education solutions, educational tourism trends and presence inside virtual reality systems. Section 3 presents some methods used for project development, followed by Sect. 4 that presents the expected results.

2 Literature Review

2.1 Digital Education Solutions

Virtual Learning Environment (VLE) is typically a web-based platform for the digital aspects of unit courses in educational institutions. It uses entertainment to provide natural and interesting learning through digital content of the lessons and materials in a way that makes it interesting and interactive to students, so they can learn while playing games, or in a joyful way (Pan et al., 2006). Some concepts of the E-learning can be intended for a VR platform, such as the interactive problem-solving exercises to reinforce the exposed material, the learning engagement, and administration (for tracking of progress and achievement of the user with the application). However, beyond the VLE digital resources, VR can make use of a great variety of digital assets such as informative text, audio, graphics, photos, video, panoramic-images, 360 Videos, 3D Models, in an immersive way and with an unusual interaction. According to the Taxén and Naeve (2002) "VR systems have the potential to allow learners to discover and experience objects and phenomena in ways that they cannot do in real life" (p. 1). Further, "VR/AR-based systems were more effective in improving student motivation and satisfaction than traditional ones, especially for situated, inquiry based and self-regulated learning" (Yung & Khoo-Lattimore, 2019, p. 2059).

Indeed, VR can be a good platform to offer digital solutions to enhance the learning experience, as well as in the purpose of this work in the ET context, serving as a new digital communication tool. By providing the synergy between three-dimensional virtual worlds with quizzes and polls run through the informative virtual platform, as in VLE (Pan et al., 2006), it can provide different interactions and unique immersion to the users senses. This enables users to have a better presence to the exposed content and learn in a different way from any other technologies such as television, books, or online web-based platforms.

Besides that, the immersion effects can turn towards behavioral intentions, leading users to have a preview of the ET content of the region and thus creating the desire to visit the real place (Hosanya & Martin, 2011). VR applied as an educational tool can generate greater interaction between the students and the visited environment, ensuring greater knowledge from the remote region and allowing discoveries, new interactions, and creating memories through an emotional connection (Pan et al., 2006; Rainoldi et al., 2018).

2.2 Marketing Strategy and Tourism

Technology is involved in many areas of marketing, and as it adapts and evolves, new tools such as VR and Augmented Reality (AR) has been used in new Marketing Strategies (MS) (Gallardo et al., 2018). Recent applications of VR in this field suggest that the use of VEs allow a better level of immersion to the user, thereby facilitating the development of “E-tourism”. This enables a unique interaction for tourists, a virtual scenario in which users can share experiences, observations, recommendations and also interactions with each other (Gallardo et al., 2018).

According to Guttentag (2010), VE applications that duplicate real-world sites or objects will be particularly prevalent among those used in tourism. Since VR allows the creation of realistic VEs, tour planners can analyze when they consider taking advantage of it, as it can serve as a tool to communicate the touristic plan or to allow consumer’s feedback from the virtual experience. Thus, VR is also suggested as a replacement for the actual website visualization and the travel planning package checking. VR can contribute to natural and cultural sites preservation (Tussyadiah et al., 2017), also as a tool for sustainability and communication.

Studies suggest that VR is a potential tool for Experiential Marketing (EM) since technology allows potential tourists a “try before you buy” experience in visiting a specific location (Tussyadiah et al., 2017). Moreover, when VR is equipped with interactive visualization and applied in virtual tourism experiences, is a good tool that affects tourist’s trip planning, therefore influencing the tourism industry (Huang et al., 2015). Guttentag (2010) suggested in a study that VR technologies can provide a range of applications to tourism professionals in terms of tourism policy planning, tourism marketing, tourist attractions, entertainment, and heritage tourism site preservation.

Despite VR acceptance in destination marketing is still barely explored, VR can be a good technology in the marketing strategy applied in tourism. This growing trend is incorporating multimedia to better assist tourism marketers in creating a “memorable experience that integrates meaning, perception, consumption, and brand loyalty” Williams (2006, as cited in Huang et al., 2015, p. 117).

In regards to the phases of the Customer Buying Cycle (CBC), VR has huge participation in the phase of stimulation (i.e. problem recognition) for touristic agencies (Rainoldi et al., 2018). The stimulation phase is particularly important to show the benefits and qualities of the touristic services and the value of the destination region. By applying VR in the stimulation phase, the destinations can have a great influence through the emotional-connection and information search process for potential or repeated tourists.

Moreover, VR allows accurate and reliable information in a fraction of cost, time, and effort compared to the traditional promotional material, thereby enhancing the decision-making process of the potential consumers (Rainoldi et al., 2018). Whereas the Technology Acceptance Model (TAM) has great importance on how technological innovation can transform the structure of how we consume, accept, and use technology. EM can greatly benefit from the study model and apply it to many strategic segmentations.

TAM has a preposition that behavioral intention is influenced by the attitude which is typically the general impression of the technology (Kim & Michael, 2019). When users are presented with new technology, a number of factors influence their decision about how and when they will use it, remarkably:

(i) Perceived usefulness (PU)—defined as "the degree of which a person believes that using a particular system would enhance his or her job performance". That is, whether or not someone perceives the technology to be useful for what it intends and
(ii) Perceived ease-of-use (PEOU)—defined as "the degree to which a person believes that using a particular system would be free from effort" Davis (1989, as cited in Kim & Michael, 2019).

In other words, the easiest to use a new technology the better. If it's not easy to use or if the interface is complicated, or any other aspect, there's no positive attitude towards it and no acceptance by the final consumer. For this reason, tourism marketers must know your target audience before adopting a virtual EM.

2.3 Enhancing Presence

Presence, involvement, and immersion are widely discussed among researchers and developers and their influence on VR systems (Tussyadiah et al., 2018; Schuemie et al., 2001; Witmer and Singer, 1998; Rose et al., 2005). According to Witmer & Singer (1998) presence in VE is defined as "the subjective experience of being in one place or environment, even when one is physically situated in another" (p. 225). The VR immersion enables the ability to perceive the relationship between oneself and the 3D environment built around.

A study has shown that the longer the VR sessions, the higher was the sense of immersion and presence (Yung & Khoo-Lattimore, 2019). For this reason, VR is beginning to be used also in therapy (Carlin et al., 1997; Botella et al., 2004; Witmer & Singer, 1998) but research on the effect it has on the human psyche is still scarce. Even though the sense of presence in VR (Carlin et al., 1997; Schuemie et al., 2001; Botella et al., 2004) can lead to exploring the treatments for mental conditions such as anxiety and specific phobias. Virtual Reality Exposure Therapy (VRET) is classified as a virtual treatment that has been applied to fear of spiders (Carlin et al., 1997) and flying phobia (Botella et al., 2004). Beyond that, VR has been used in neuropsychology, for the assessment and rehabilitation of disabilities that result from brain injury, attention deficits (Rose et al., 2005), and stroke rehabilitation (Jack et al., 2001; Laver et al., 2012).

Indeed, presence can be a key factor to influence behavioral responses to the virtual stimuli hereby is also discussed in tourism (Huang et al., 2015; Tussyadiah et al., 2018; Yung & Khoo-Lattimore, 2019). The Presence theory identifies that immersion and involvement are the two main characteristics that enhance the user experience in a VR environment (Yung & Khoo-Lattimore, 2019; Witmer & Singer, 1998). Moreover, the effectiveness of the communication is related with presence, so for tourism marketers to understand how to create the desire in VR consumers to "buy the destination trip" or the influential factors that affect virtual tourist's trip planning, some key points must be known before the development of an experiential VR marketing.

TAM, as mentioned before, and self-determination theory (SDT) (Deci & Ryan, 2015; Ryan & Deci, 2000) are found to be useful to study the influence of presence in VR systems and factors that influence the flow-state (Kim & Michael, 2019), both can be useful frameworks to guide the present study. Some of the reasons to create a VR experience are to build memorable experiences that integrate meaning, influence perception, and consumption (Tussyadiah et al., 2018). SDT is very often applied for examining human motivational behavior and it has been applied for explaining the motivational dynamics in the human psyche (Deci & Ryan, 2015). The theory supports the idea that when people are guided by their needs for autonomy, which is their own behavior, it extends the satisfaction of psychological needs which determines the underlying motivational mechanism of the individuals to pursue an activity and thus directs people's behavior (Huang et al., 2015; Ryan & Deci, 2000).

Since VR is suggested to provide various applications in terms of tourism attractions, entertainment, and heritage tourism site preservation (Guttentag, 2010). And, as VR provides a unique way to obtain information through immersion and multisensory modalities, it also enables users to perceive a realistic representation of the destination travel (Tussyadiah et al., 2018). It's plausible to explore more such technology in this sector since its affordances can provide different action-supportive information on what users "could do or see" when being in the touristic destination region.

Moreover, as Huang et al. (2015) suggest, virtual tourism developers should provide an effective platform for communicating the information that will lead to a more enjoyable experience and travel intentions. In the case of the present work, it's important to highlight that the psychological needs of satisfaction though enjoyment is in alignment to raise awareness of environmental issues of the visitors of CCVB. Thus, we aim to analyze the effect that has Augmented Virtuality (AV) on the VR experience as an EM tool. Also for contributing to foster the information in AV which is the less studied technology within the reality–virtuality continuum (Milgram et al., 1994) (Fig. 1).

AV is based on a VE or a computer-generated scenario that integrates real components, like tangible objects of the "real world" (i.e., items, people, body, hands) (Neges et al., 2018; Farshid et al., 2018). Therefore, additional registration is necessary to integrate both parts of reality–virtuality continuum axis (Milgram et al., 1994) and to "augment the virtual with real objects".

Realistic haptic feedback is also necessary and is one of the biggest challenges of an AV environment (Neges et al., 2018). The tracking and registration must match its position within the VR scene. So, as the present work suggests, the user's hands detection must be continuous and with dynamic tracking. This enables the user's hand

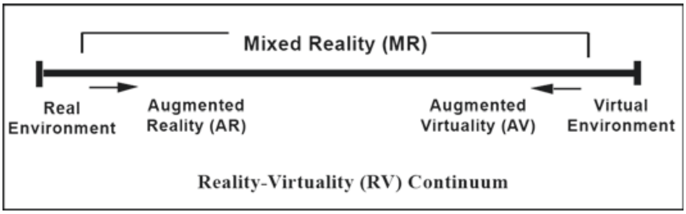

Fig. 1 Reality–virtuality continuum (Milgram et al., 1994)

interaction with the content inside a 360 VR video-application within the destination trip being a different approach on EM and leading to a distinct mental construction or perception of the educational touristic region. Which is also dependent on possible actions and information shown in the VR platform. This is also in alignment with some of the factors discussed (Witmer & Singer, 1998) that can contribute to a better sense of presence in VE, such as:

- **Control factors**: the amount of control the user has on events;
- **Sensory factors**: the quality, number and consistency of displays;
- **Distraction factors**: the degree of distraction by objects and events in real world;
- **Realism factors**: the degree of realism or resolution of the portrayed VR headset.

The control factors can be a good starting point with AV to enhance a user's presence inside a VR system, also in a more enjoyable experience. The more the VR experience is controlled by the system, the more the user is not immersed. The control factors (Witmer & Singer, 1998) are also in alignment with SDT—Autonomous motivation, which is "typically accompanied by the experience of positive affect, flexibility, and choice. In contrast, when people's motivation is controlled, they act out of coercion, seduction, or obligation. They tend to experience pressure and compulsion, rather than concurrence and choice" (Deci & Ryan, 2015, p. 486).

So, in the case of 360 interactive videos, which is also "currently absent from the review of the literature" (Yung & Khoo-Lattimore, 2019) this would be a larger step. However, there are still some technology deadlocks with the 360 VR teaser's view limited by 3 Degrees of freedom. The user cannot walk in 360 Video footage as in a three-dimensional world computer generated. This justifies the reason to use the "Virtual Tours" or hotspot's interaction. Companies could also use AV to enhance the customer experience, not only by manipulating the visual experience but also the stimulation of other sensory systems (as smell, taste, audio, or touch) (Farshid et al., 2018).

Although limited, the present work suggests other kinds of interaction, also in alignment with the Distraction factors (Witmer & Singer, 1998). Our approach is to use 3D models with 360 VR Video and AV (i.e., hand's interaction) to influence psychological needs of satisfaction and enhance the CCV visitors' virtual experience with enjoyment and involvement.

The hand's interaction can be more natural than controllers, leading to a better perception of self-inclusion and self-movement (Witmer & Singer, 1998) and can

Fig. 2 Douro ecological-VR—virtual buttons with hands interaction

be suggested as a different activity that can enhance the sense of autonomy (Füller et al., 2009, 2011) as cited in Huang et al. (2015, p. 123). If the visitors find the interaction awkward with the VR controls, the immersion would be reduced, so this can be a good differential on MS. Once, the virtual hands can also instigate Intrinsic Motivations (Deci & Ryan, 2015) whereas people are so engaging in the experience because they find it interesting, enjoyable, different, or funny (Fig. 2).

For this reason, the present work also aims to explore 3D characters and 3D objects interaction, such as the 3D interactive virtual button with specific function for each VR scene. The same as when young children are playing they are active and engaged in a very natural way "they are simply doing what they find interesting to do, and in the process, they are learning and growing" (Deci & Ryan, 2015, p. 487). Similarly, 3D Models interaction can be another influenceable factor in presence. In regards to distraction and control as already shown in the study that "synthetic characters with emotions and personality have a powerful ability to capture and hold students' attention" (Pan et al., 2006, p. 22).

Thus, 3D characters can capture and hold the tourist visitors due to the fact that it will not be necessary to create motivation to what they already find it intrinsically interesting to do, thereby possibly enhancing their attention and desire to visit the real destination. Also, in gaining knowledge and information about the animals of the region which is typically hardly seen. The models can resolve the gap in recording the original fauna of Douro's region by the 360 Camera.

3 Methods

The present study aims to clarify new means of tourist attraction, specifically for the Douro's region by analyzing the factors that enhance and influence the presence and the assimilation of information inside a VR system. This project aims to foster learning and scientific knowledge related to environmental issues for the science center visitors, and for promoting an educational destination travel. Further, the project explores tourists' experience of VR and analyzes the feedback of other aspects of interaction such as haptic interaction, animated-characters and 3D objects.

The project consists of the exploration of 360 3D recordings of Douro's region, post-process, and quality treatment edition through Adobe Premiere Pro and its usage into the rendering-gear of the Unity3D platform. FFMpeg, h-265 Video Codec, Spatial Media Metadata Injector, Adobe Media Encoder, Photoshop and After Effects were also used in order for the video and images treatment. Beyond that, it consists in the VR interactive application development and the deployment into the Oculus Quest device. The 360 3D content and its usage with Unity3D, Premiere Pro and Quest were limited by the resolution, we use a specific resolution for the video (2880 $\times$ 5760) h265 codec on Oculus Quest and 6400 $\times$ 6400 pixels resolution for 360 3D Images.

The application is being hosted in September/2020 by Bragança Ciência Viva Science Center and defined as one of the permanent interactive science exhibitions that enhances ecosystem values awareness. This provides science center visitors an entertaining and educational tour, allowing remote educational tourism and providing key concepts of virtual environmental education regarding the valorization of natural resources of the region.

The 360 3D video footage is taken with the Insta 360 Pro camera with depth sensation noticed when using the VR headset. While navigating the 3D Virtual Tour, the psychological needs of autonomy and relatedness are relevant to the consumer experience and behavioral intentions. Therefore, in order to enhance the presence and immersion levels inside the VR environment, the recognition of the user's hands were implemented by using the SDK—Oculus Interaction from Facebook.

Interactive virtual buttons and hotspots were developed in order to allow users to interact with each VR scene. Each interaction enables the freedom of choice of the user whereas the user could choose to watch a 360 movie, to interact inside a Virtual 3D Tour or with 3D animals of Douro's region (Fig. 3).

Fig. 3 Douro ecological-VR—user's view

4 Expected Results

By combining the immersive 360 VR interaction with 3D objects, educational tourism and science communication techniques, it is expected to improve the users learning experience regarding environmental education topics and scientific concepts. Besides the EM strategy review based on VR-systems. The use of the VLE applied in remote environmental educational tourism contributes to the world's efforts in enhancing natural values of key regions, environmental care, and science education for heterogeneous audiences. Which also applies in the current context of social distance in 2020 by Covid-19 in educational institutions.

Right after the VR experience, participants will be requested to complete a short digital questionnaire with qualitative answers (0–5 levels of satisfaction), and questions focused on defining the groups (age, genre and nationality), as well as their experience (i.e. "Did the experience increase your desire to visit the real region?", "How real was interacting with the 3D animals", "How do you evaluate the exhibit as a tool with educational entertainment?", "Did you feel the desire to protect the animals or their habitat?", "Did you feel safe and comfortable when using VR glasses?", "Did you feel pleased when interacting with the 3D animals", "The experience of interaction with animations increase the level of interest or level of information in the educational subjects covered?", "Which environmental topics were better shown").

These questions are focused on defining the VR/AV experience as a good tool for raising environmental-issues awareness through emotional connection and as an interactive educational entertainment to influence educational tourism planning, as well as serving as an EM tool. All the answers will be saved in a database online web server, and crossed with the previous visitor's data, as their expectations about the tour, the desire to visit the region, and learning in order to evaluate the success of the exhibit with the institutions' target groups.

5 Conclusions and Future Work

VR technology applications display to users a different immersive and involvement way for learning, by allowing AV interaction experiences, it can also enhance participants' attention to the approached topics in an entertaining way. The use of VLE applications can allow remote educational tourism context, as well as serving as a solution for the current 2020s context of coronavirus pandemic. Users can have a unique learning approach to relevant environmental topics of different locations, with scientific accuracy, highlighting the region's natural values, and enhancing participant's environmental awareness.

The learning curve is also covered by the present research and it can increase through entertainment and emotional connection with VR, thus, the present work will be still under analysis after its implementation in the science center and its extension by adding more 3D animated-characters and having visitors feedback.

The project also allows for future partnerships between other educational institutions, enriching international partnerships, already in Portugal and Spain, and developing new technologies regarding VR solutions, educational tourism, and environmental education.

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VR and Nostalgia: Using Animation Content at Theme Parks to Boost Visitor Experience

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Abstract Interviews with experts and visitors conducted using a convenience sampling method were combined with archival research to understand the effect of adding VR technology to Korean theme park attractions, as well as to look at how nostalgic attributes in animation content can enhance the immersive experiences of the visitors. The interviews showed that having sophisticated, narrative driven, high-quality content is more important to visitors than the extent to which the VR technology is state-of-the-art. Findings also suggest that adopting existing well-known animation content to VR attractions will result in visitors experiencing better emotional connectedness, enhanced presence, and fuller immersion. Finally, ensuring that the quality-driven VR content evokes nostalgia will lead to repeat visitation by visitors.

Keywords VR · Animation · Nostalgia · Theme park · Lotte world

1 Introduction

The theme park industry has experienced tremendous change recently. Technology has been advanced in order to appeal to more guests by providing an immersive experience, with virtual reality (VR) being one of the most highly adopted innovations. At theme parks, visitors enjoy virtually tailored attractions incorporating animation or movie content. With strong storytelling and content, the audience can be induced to conjure up strong individual memories and be influenced in their decision as to whether to revisit (Oh & Ma, 2018). Thus, the design of a VR attraction can have important strategic implications (Uriely, 2005) for an industry that has long searched for ways to provide visitors with more memorable experiences (Christou et al., 2018) and to motivate them to visit specific destinations (Hsu et al., 2007; Yoon & Uysal, 2005).

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In order to evoke strong memories, according to the interview with Mr. Chris Yoshii who is a vice president of AECOM Asia Pacific, software (theme and content) must not be neglected in the focus on hardware (rollercoaster rides, etc.). Strong memories are evoked by a stimulus that not only provides a heightened immersive experience, but also has the nostalgic attributes of inducing sentimental feelings and promoting emotional connectedness (Oh, 2013). If the media content in a VR attraction is filled with these nostalgic components, viewers will more likely become emotionally attached and interested in it. If, however, a park has no robust theme, and relies instead on simply enhancing old-fashioned attractions such as rollercoasters and water rides with VR, no strong emotional connection will result (Oh & Ma, 2018).

Animated films by themselves often have a nostalgic effect that can be amplified when their content is part of a theme park setting. Animation content creates and materializes fantasy; it provides a surreal effect and non-reality that delights its audience (Oh, 2013). Such a capacity for creating a new reality brings to mind Umberto Eco's statement that theme parks are the perfect fake environment to recreate a perfect reality (Eco, 1990). Oh and Ma (2018) postulate that Eco's view of theme parks is associated with the ability of animation to realistically mimic reality. Jean Baudrillard (1994) adds that a theme park is also a place where people perceive the blurriness between reality and its representation, the world of hyper-reality and simulation.

In the course of this research, expert interviews and archival research were conducted to explore how marrying together VR applications, quality animation content, and nostalgia can produce an enhanced and immersive audience experience, and repeated visits, in a theme park setting.

2 Literature Review

2.1 The Use of VR in Theme Park Attractions

The theme park has been considered the originator of the imaginary as virtual reality (Baudrillard, 1996) since the first Disneyland opened in Anaheim, California in 1955. Disneyland theme parks started telling animation stories within their attractions through film techniques comprised of sequences of full shots, medium shots, and close-up shots, much like the cinematography of a film (Hine, 1986). Parks have since adopted ride simulators, VR technology, and a variety of state-of-the-art attractions, ranging from dark rides such as Peter Pan's Flight to mechatronic puppets such as Animatronics (Levine, 2018). With these high-end technologies, theme parks are able to provide visitors with quality-oriented immersive experiences that tell stories more effectively than ever before (Clavé, 2007).

People visit theme parks to forget about their mundane daily lives, and to meet their favorite animation characters from childhood and interact with them within a specially designed space. These interactions evoke nostalgic memories and generate emotion, and the memories can be rediscovered by the visitors themselves through fantasy (Francois Barre, qtd. in King & O'Boyle, 2015, p. 26). VR technology can enrich a visitor's experience of materializing the fantasy when high-quality content is featured.

Theme parks that employ VR technology are attractive to both the industry and to guests who enjoy motion simulation rides that incorporate media content (Chang and Kim, 2018). Kim (2016) noted "the power of VR to easily create simulacra, stimulate various senses, increase the feeling of immersion, synchronize motion with storytelling, communicate interactively, change themes easily, provide physical stability, and save space" (p. 42). Simply speaking, VR enhances the experience of theme park attractions (Jerald, 2016). A virtual environment helps theme park visitors become immersed in the attractions, and the quality of the VR content (Hopf et al., 2020) can create a heightened feeling of fantasy (Swartznan, 1995) and an intensified sense of presence.

2.2 Animation and VR Content to Evoke Visitor Nostalgia

Animation itself is virtual reality created by illusion and fantasy. Wells (1998) notes that animation as a medium is completely fake because it has 'no real camera to record reality but artificially creates and records its own' (p. 25). It creates many different characters and brings them to life by an illusion of movement (Wells, 1998), which is why memories of familiar animation characters from childhood persist into adulthood.

According to Alistair Swale (2015), nostalgia is about conjuring familiar personal events or historical events that have nothing to do with personal memories. Walden (2018) argues that animation helps us to reminisce about the past, and it can represent dimensions of different types of memories, including nostalgia. Animation, with its artistic style and story, can cause personal memory to become warmer and filled with longing. Boym (2001) points out that nostalgia is not only longing for a place, but also yearning for childhood. Animation, due to the nature of the medium, allows audiences to immerse themselves in personal and historical nostalgia through the animators' use of aesthetical elements. Hence, employing animation content via a VR application in a theme park setting evokes personal nostalgia of childhood memories.

Theme parks began providing VR and surreal experiences via cinematic imageries on rollercoasters at a very early stage (Levine, 2018). Hine (1986) states that Disneyland's The Magic Kingdom was not designed by architects, but by animators: not as a group of buildings, but as an immersive experience. It was "a movie that could be walked into." (Hine, 1986, p.151) Animators were able to imagine and embed non-physical animation fantasy into physical attractions right from the initial planning stage (Clavé, 2007, p.17). Another special aspect of the theme park environment is that visitors interact with animation characters—who never grow old or die—and thereby experience a nostalgic trigger based on their own memories (Oh & Ma, 2018). With characters that are forever young, an audience can go back to an earlier time that is no longer accessible to them. Visitor emotions and fantasies can be realized and strengthened by themed attractions that are comprehensively and strategically designed and controlled. Recent technological advancements in the VR field, such as Head-Mounted Displays (HMD) with immersive environmental settings, can be used to magnify feelings of nostalgia and create an enhanced visitor experience (Huang et al., 2020).

2.3 VR Attractions at Korean Theme Parks

Theme parks in Korea have invested in new attractions, new high-end technologies, and more events as strategies to attract more visitors (Lee, 2019); the experts cited all emphasize that creating emotional attachment with strong content is a top priority. The director of EVR Studio Seoul, Jae-Wook Park, states that producing high-quality customized content for a VR attraction is critical (2020), not only in Korean theme parks but also for other countries. Applying VR technology to theme parks in Korea, however, is especially challenging because the kind of robust content needed to provide a prolonged and heightened immersive visitor experiences is still lacking (Oh & Ma, 2018). Additionally, Mr. Park stresses that merging existing motion-based systems with VR technology requires content that is designed to perfectly follow the motion (Nelson, 2016) However, it is challenging to create even 1–2 min of computer-generated animation perfectly synchronized with an audience's field of vision and movement, without causing vertigo (Ma, 2017).

In 2016, the Lotte World theme park in Korea opened its VR rollercoasters, 'French Revolution 2 VR', 'Gyro Drop 2 VR,' and 'Across Dark.' Seung-Yeon Lee, the head of Lotte World's VR business team, explains that they introduced VR because it is easy, interactive, fast, flexible, effective, and low cost (Shim, 2017). Lee also believes that applying VR to existing attractions has, at least in the short run, the same impact as introducing entirely new attractions (Shim, 2017). However, a number of researchers have expressed concern that simply adding a new technology without solid content storytelling will not attract long-term guests or guarantee revisits (Kim, 2016; Kim & Han, 2017; Chang & Kim, 2018). VR attractions in Korean theme parks do not display any narrative strategies, which requires thorough planning and development. According to the Korean VR & AR Market Report from the Korea Institute of Intellectual Property (Yim, 2019), facilities that provide VR experiences have not yet emerged as a market and thus still need funding support from the Korean government. The VR field in Korea is still in its infant stage, and it will require time and much effort to create high quality content that can mesh well with the technology in a Korean theme park context.

2.4 Theoretical Framework

Several elements go into an effective story telling environment. Unification provides coherency by using a consistent style of architecture and atmosphere throughout, in the attractions as well as in secondary locations such as food and retail outlets. Mise-en-scène encompasses all aspects of the general surroundings which makes visitors feel as if they are inside a movie. Dépaysement is a component of Surrealism that creates a mysterious or strange encounter with a realistic object in an alienated place. These three elements, enhanced by VR, are the external stimuli that support the immersive experience and sense of presence that visitors long for.

Choi (2017) suggests that a unified design with a strong theme is the most fundamental and vital attribute for storytelling in theme parks. He particularly highlights the 'theme' aspect of the message that the theme park designer wants to convey, as that message creates a park's distinctiveness. A unified structure helps the story express the theme more efficiently.

Chazaud (1998) argues that the theme must be rich enough to demonstrate mise-en-scène as a whole. A holistic design that gives the audience a cinematic experience is crucial in order to provide coherent and unified characteristics within the identity of the park. The theme must also be versatile regarding the visitors, media content (animation), and entertainment, and it must cater to the visitors via scenic or dramatic stages. The contribution of mise-en-scène is to create key elements such as dépaysement, escapism, fantasy, imagination, immersion, nostalgia, surrealism, and verisimilitude. Mise-en-scène is one of the most important factors in producing the right atmosphere for a theme park.

King (1981, 837) writes that the "theme park is a social artwork designed as a four-dimensional symbolic landscape to evoke impressions of places and times, real or imaginary." King also emphasizes that a theme park should not simply add random rides, but that it needs to be planned thoroughly to secure its thematic integrity (King & O'Boyle, 2015). The theme must be unified to provide visitors with a complete fantasy. This echoes Coltier's definition (1985, 24), which specifies the theme park as "a closed universe whose purpose is to succeed in the encounter between the dreamy atmosphere it creates and the visitor's desire for dépaysement." The biggest goal of visiting a theme park or any other touristic destination is to remove tourists from their mundane lives, in other words, escapism (Huang et al., 2020).

Oh and Ma argue that using animation content in theme parks is an effective way to create dépaysement, as there are overlapping factors between the two media. The commonalities between theme park attractions and animation narratives are (1) fantasy, (2) immersion, and (3) verisimilitude (Oh & Ma, 2018). These attributes strengthen the original purpose of theme parks—escapism, imagination, and nostalgia—resulting in a stronger theme.

Cho (2012) describes a theme park as a sensational space where visitors can experience an exciting fantasy, and where animation characters can be a significant element in delivering the desired image of the space. In other words, there is an inseparable relationship between a theme park and its animation characters, with the characters manifesting their identity through the park.

Oh (2013) postulates that many global theme park attractions are successful because they have adopted animated content that generates emotion by evoking visitors' nostalgic memories of animation characters. These feelings of nostalgia are triggered by the narratives that the theme parks provide, and are based on each individual visitor's memories. In turn, media memory can be rediscovered by the audience members themselves through fantasy (Francois Barre, qtd. in King & O'Boyle, 2015, p. 26).

Wei et al. (2019) posit that VR technology can enhance the feeling of distinctiveness by focusing on presence, which leads to higher level of interest. Presence in an immersive environment allows visitors to experience something intangible with multisensory involvement, and has been shown to lead to re-visitation.

3 Methodology

The aim of this study is to investigate the importance of nostalgic animation content in immersive theme park environments that use VR applications for creating emotional engagement in their visitors. The study is focused on Korean theme parks which have added VR technology to their animation-based attractions. In the cases studied, the animation content was specific for each attraction and did not involve existing content that would have been previously seen on TV or in theatres.

Preliminary interviews with theme park professionals Mr. Paul Pei (former Executive Director of Ocean Park) and Mr. Chris Yoshii (Vice President of AECOM Asia Pacific) were conducted in Hong Kong during previous studies to gather insights on what makes theme parks strong. An additional interview was conducted with Mr. Jae-Wook Park (Director of EVR Studio, Seoul, South Korea) and two other park professionals who did not want their identities revealed, to describe the function of VR at Korean theme parks. The spread of covid-19 prevented additional in-person interviews, so email interviews were conducted using convenience samples of three experts (from Lotte World Adventure and Everland) and ten visitors. The information gained from the interviews was supplemented with archival research consisting of news and interview articles, media reports, and books referring to Lotte World and Everland.

In the email interviews, the same set of six open-ended questions were given to the experts, who are all former or current members of the theme park industry, and the visitors. The interview questions were both descriptive and exploratory, and covered two dimensions: (1) How does each park develop strategies to attract more visitors? Do park professionals/designers consider nostalgia to be an important factor? How does virtual reality in particular work as an amplifier to attract more visitors to theme parks? and (2) What kinds of virtual reality content have been adopted, and have these measures been successful?

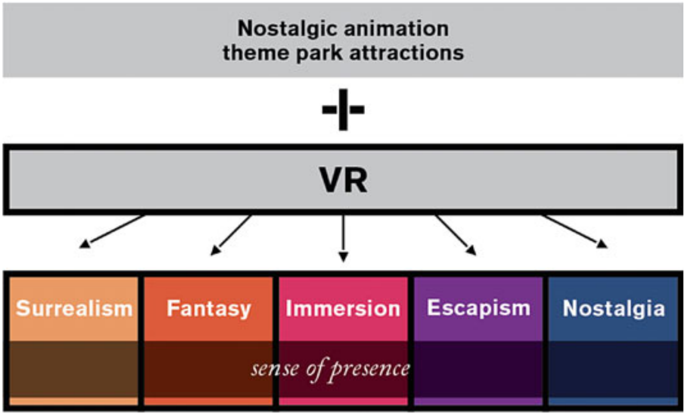

Fig. 1 Conceptual framework showing the significant elements for a successful immersive environment for a theme park

A preliminary conceptual model was developed to describe successful theme park elements with nostalgic animation content and VR technology, based on the literature cited above. The model is shown in Fig. 1. It was employed during the interviews and archival research.

4 Results and Findings

The interviews consisted of the following six questions:

Q1 What is the most important attribute for a VR attraction?
Q2 What are problems they have with VR attractions?
Q3 What is their repeat visitation like?
Q4 What are technical issues?
Q5 Are there any synch-in problems between the media content and the movement?
Q6 What kind of content are they using? Is it high-quality and able to evoke reminiscent memories?

Table 1 gives a summary of the results from the interviews.
Several important themes emerge from the interviews.

- Content quality: Experts and customers both stressed that content quality is the most important attribute for a VR attraction. In fact, having sophisticated, narrative driven, high-quality content seems more important to visitors than the extent to which the VR technology is state-of-the-art.
- Waiting time: Experts and customers agreed that the waiting times for VR attractions are too long.

Table 1 Interview summary

	Coded replies		Themes
Interview question	Park and media experts	Customers	
Q1	• Content quality • Entertainment value • Waiting time	• Content quality • Waiting time • User feedback on internet	Content quality Waiting time
Q2	• Waiting time • Safety • Hygiene • Dizziness • Content quality	• Dizziness • Waiting time • Hygiene • Content quality	Waiting time Dizziness Hygiene
Q3	• Few repeat visitations	• Once is enough • Dizziness	Few repeat visitations
Q4	• Relying on headset only	• Headset is uncomfortable (size and fragility issues)	Limited resources
Q5	• Dizziness	• Dizziness and nausea	Giddy and unwell
Q6	• Using completely new media content • Audience has never seen the content before	• No memories to reminisce over • Has never seen the content before	No nostalgic feeling evoked No emotional linkage

- Dizziness, giddiness, and feeling unwell: Some visitors said that they feel uncomfortable and dizzy when using the headset, even on the main park attractions. The respondents believe that the dizzy feelings are caused by synch-in problems between the media content and the motion of the rides.
- Hygiene: Some visitors said that they do not feel that the headset is clean enough, and some even felt that wiping the headset after each session does not suffice.
- Neither nostalgia nor emotional attachment is being evoked: Since these theme parks do not make use of existing content which would be well known to the visitors, there is no mechanism for accessing their memories and inducing reminiscences.
- Limited resources: Because of time and cost restraints, the parks that were studied added VR to existing attractions rather than introducing entirely new attractions. While the experts believe that this was a smart strategy, the visitors feel that there are too many issues with the headsets as a result.
- Repeat visitations: Experts and customers are well aware that the theme park attractions are not yet compelling enough to warrant repeat visits. The reasons include those listed above.

According to the interview session with Mr. Park (EVR studio) and Levine (2018), the most pressing challenge in applying VR technology to theme park attractions is the production of high-quality content. Content quality at the newly launched VR attractions at the two theme parks that were studied is not up to standard for those who have experienced the attractions at other global theme park chains. Visitors did not complain about the special effects; however, they described weak narratives and confusing plots. They noted that they would prefer interacting with popular, existing content rather than with content with which they have no prior attachment.

Previous research shows that the lack of attractive, strong content hinders re-visitation (Ma, 2017). Our interview findings are consistent, showing that the park visitors were curious enough to try the newly added technology, but VR applications simply added to existing attractions such as roller coasters or gyro drop rides were not sufficient to motivate the visitors to return.

Our interviews also show that there are two other factors that affect re-visitation. One is visitor discomfort in cases of poorly created content that does not properly synchronize with the movement of the rides (Ma, 2017). The other is that headsets can have hygienic and size issues, where, for example, the cleaning standard by the staff does not provide security to the visitors, and the headset is not adjustable for different head sizes.

5 Discussion and Conclusions

Our research has reinforced the understanding that satisfying visitor expectations and producing repeat visitation only occur when theme parks deliver a solid holistic concept which integrates characters and technology while providing guests with the opportunity to have limitless imagination within the theme of the park (Lim 2012). VR deepens the immersive experience when it is combined with quality-driven content because complete immersion does not solely depend on technology; it must also resonate with the cognitive psychology of the VR users and the sensory system. Unfortunately, while VR technology continues to advance and evolve, the quality of its content has not yet become a central focus (Kim & Han, 2017; Chang & Kim, 2018). Visitors who are already familiar with VR media at global theme park chains require higher quality content than is currently available in Korean theme parks.

Other findings from this study include the importance of the correct setting for a VR experience, whether it be a rollercoaster or theater, and the need to reassure visitors as to the standards of hygiene being followed, especially with respect to the headset (which is not disposable and needs to be used by many people). A possible solution for hygiene reassurance might be providing disposable eye patches, which protect visitors from direct contact with the headset.

The findings of this study are necessarily limited, due to the current pandemic situation; the author was only able to conduct email interviews and could include only a small number of interviewees. Although archival research supplemented the gap, participant demographics in future studies need to be wider in terms of nationality, occupation, ethnicity, age, and gender.

While this study does not cover the general perception of VR applications in theme parks, it does emphasize the ability of high-quality animation content to immerse its visitors into a fantastic, surreal, and immersive experience within a hyper-realistic space. For maximum immersion, a VR experience must appeal to the senses, the imagination, and the emotions. Animation can indeed offer this kind of fantastic experience, which embodies the viewer's emotional state (Huang et al., 2020). To achieve such an experience, we recommend that theme parks build on the fundamentals of establishing strong, recognizable themes using well-known animation characters to induce nostalgia and thus magnify each visitor's unique memories (Clavé, 2007; Christou et al., 2018).

Future research on adopting VR in theme parks could further examine connections between strong content in the context of an overall holistic approach to the immersive experience, and the psychological impact when this approach is supported by VR technology. In order for visitors to be able to be immersed in the experience, theme park operators need to provide their customers opportunities that appeal to their imagination, and this requires appealing and clearly defined themes with a strong encircling and supporting narrative. In many cases, Korean theme park operators have yet to recognize the need for this holistic approach.

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