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POTENTIAL USAGES OF VIRTUAL REALITY IN DESIGN RESEARCH AND PRACTICE – A REVIEW

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ABSTRACT: Besides application fields such as entertainment and marketing, the technology of Virtual Reality is also applied in research and practice, including domains such as automotive, architecture, and construction. Furthermore, VR has been utilized for several activities in design practice and design research. However, the impact of this technology on design as a profession remains to be investigated. Thus, in the present study, an integrative literature review is presented to investigate the potential impact of Virtual Reality on design research and design practice. The findings indicate potential advantages on different levels. VR has the potential to enhance problem identification due to laboratorial environments and to foster co-creation due to enhanced motivation and the establishment of synergies between the involved stakeholders. Furthermore, it supports prototyping activities due to its capabilities for realistic scaling and perspectives. And lastly, VR has proven to be advantageous for design evaluations and reviews due to its visualization and immersion potential. Drawbacks of using VR for design research and practice involve technical limitations such as restricted field of view, limited performance, but also aspects such as missing accuracy for prototyping and the absence of haptic feedback. Future work will involve an extended review involving further literature and application domains.

Keywords: *Virtual Reality, Design Practice, Design Research, Design Methods*

1. PURPOSE OF THE PAPER

Virtual Reality (VR) is defined as "the computer-generated simulation of a three-dimensional image or environment that can be interacted with in a seemingly real or physical way by a person using special electronic equipment, such as a helmet with a screen inside or gloves fitted with sensors." (Oxford English Dictionaries, 2022).

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Eventhough the technology of VR already underwent a long way of development, it just entered the the end-user market less than a decade ago, with its majority applications in gaming and entertainment sector (Ivanova, 2018). Especially the COVID-19 pandemic had great impacts on digital domains such as the gaming industry and immersive technologies in a way that media and gaming consumption increased (Ellis et al., 2020). Still, VR is considered as a niche product but with great future potential both for consumers and enterprises (Deloitte, 2018).

Besides the entertainment industry, VR also finds its application in further domains such as marketing, military, healthcare and treatment, as well as industrial fields such as construction and automotive (Berg & Vance, 2016). In the automotive industry, for instance, VR is used among others for visualizations, driving simulation, design reviews throughout the product development, and ergonomic studies. One example for a marketing application in the automotive context is the "AUDI VR experience" that lets potential customers experience vehicles with any available specification and configuration with the help of head-mounted displays (HMD) (Audi, 2017).

Beyond that, VR already gained great releveance as research tool especially for exposure therapy, behavioural research and pedestrian research due to its advantages such as the conduct of experiments in safe and controlled environments, its flexibility in the creation of various scenarios, and great sense of immersion (Berg & Vance, 2016; Stadler, Cornet, & Frenkler, 2020b). Eventhough VR has already been utilized for creative tasks, participatory activities as well as tool for brainstorming, its impact on design research and design practice remains to be investigated. Thus, in the present paper, based on the analysis of a selection of 28 studies the potential impact of VR on design research and design practice is discussed.

2. KNOWLEDGE BASE

A knowledge base is shared to establish a basis for the literature review. The knowledge base covers and introduction to the topics of design practice and design research as well as an introduction to Virtual Reality and its distignuishement from other technologies such as Augmented Reality and Mixed Reality.

2.1 Design Practice

"Design is to design a design to produce a design." (Heskett, 2002). This exaggeration from Heskett (2002) symbolizes the blurriness in defining the term "Design" as such. Moreover, the definition of the mentioned terminology including its goals, objectives, and application fields is not uniform and undergoes permanent changes (based on

Götzendörfer, 2014; Hauffe, 2008). In this context, Hirsch (2014) concludes that the blurriness of the term "Design" is a result of a missing uniform definition and its protection. Simon defines design as: "[…] courses of action aimed at changing existing situations into preferred ones" (Simon, 1996, S.111). Cross (2008) states that designers are usually confronted with very poorly defined problems (i.e., wicked problems or ill-defined problems) and that the task is to come up with a well-defined solution. In this paper, the term "Design" is defined as the activity a designer carries out to develop products, services, experiences and systems out of an underlying problem, need, or idea resulting in the fulfilment of user needs as well as the needs of all involved stakeholders. To achieve this, the designer must consider aspects such as technology, sociology, ergonomics, psychology, philosophy, finance, and ecology (based on Frenkler, 2020). While designing, designers usually follow a design process, however, there are various opinions on the definition of the design process with its stages and approaches, techniques, and operations (Archer, 1984; British Design Council, 2020; Bürdek, 2005; French, 1985; Heufler, 2004; Hirsch, 2014; Lawson, 2005; Pahl & Beitz, 1996; Stadler, 2021). Moreover, while going through the design process, designers usually execute activities such as researching, prototyping, evaluating, reviewing and presenting with the help of design methods (based on Gericke & Blessing, 2012; Martin & Hanington, 2012; Stadler, 2021; Wynn & Clarkson, 2018).

2.2 Design Research

There is no uniform understanding of the definition of the term "design research" (based on Cross, 2006; Dorst, 2008; Horváth, 2004; Koskinen et al., 2012; Sanders, 2008). For Cross (2006), design research means the development, articulation and communication of design knowledge. This design knowledge can be derived from the investigation of people, processes and products. Investigating people gives insight into design behaviour and design education. Examining processes is informative for design strategies, methodologies as well as tools. In this context, Cross (2006) explicitly states that due to advances of technologies, VR needs to be considered as a design tool in the future. Horváth (2001) also defines design research as "generating knowledge about design and for design" (p.2) (as cited in Blessing & Chakrabarti, 2009, p.5). Horváth (2004) further defines it as: "[…] the instrument of exploration, description, arrangement, rationalization, and utilization of design knowledge (Pugh 1990)". *Figure 1* visualizes the understanding of the term design research for the current publication.

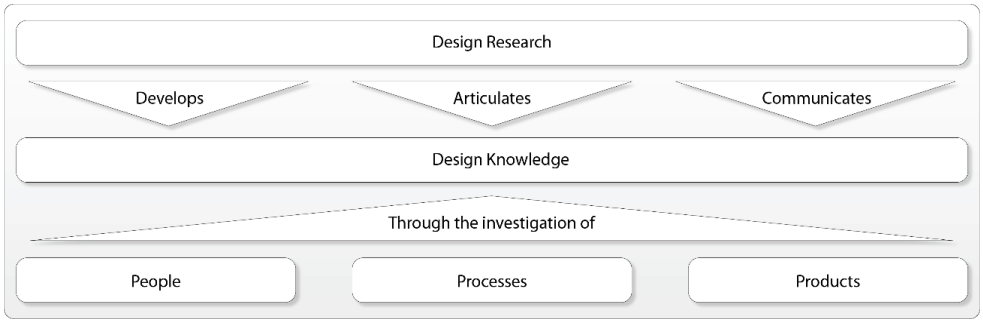

Figure 1. Design research (based on Cross, 2006)

Thus, in contrast to design practice that aims to create products, services, experiences, or systems, design research aims to develop, articulate, and communicate design knowledge that is derived through the investigation of people, processes, and products.

2.3 Virtual Reality

Considering the aforementioned definition of VR from the Oxford English Dictionaries (2022) as well as further definitions from (Cambridge Dictionary, 2022) that defines VR as "a set of images and sounds, produced by a computer, that seem to represent a place of situation that a person can take part in" and the definition of (Mihelj et al., 2013) who define VR as an interactive computer simulation that augments the user's state in a way so that the user gets immersed in a virtual world, it becomes clear that there as a consensus of defining the term in many aspects. Based on a set of definitions of the term, for the present study VR is defined as "a computer-generated simulation that can be interacted with, consisting of images, videos, and/or sound that represents an environment that the view can experience by using electronic equipment".

VR is considered as being part of Extended Realities (XR) that also comprise Augmented Reality (AR) and Mixed Reality (MR). While AR describes technologies that augment the visual field of users with digital information, MR is defined as a mixture between the real world and virtual world. Milgram and Kishimo (1994) defined a continuum for distinguishing the concepts of AR, VR, and MR (see Figure 2).

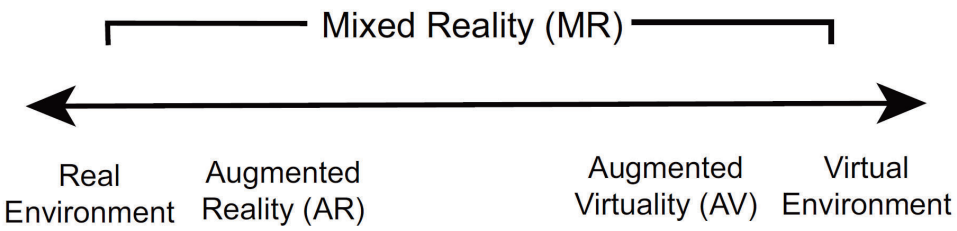

Figure 2. Relation of Extended Realities (Milgram & Kishimo, 1994)

In contrast to Milgram and Kishimo (1994), Rauschnabel et al. (2022) consider the letter "X" of the term XR as a placedholder arguing that VR does not extend reality but replaced it with digital content. *Figure 3* shows the definition of XR by (Rauschnabel et al., 2022), distinguishing the technologies into an AR-Continuum and VR-Continuum.

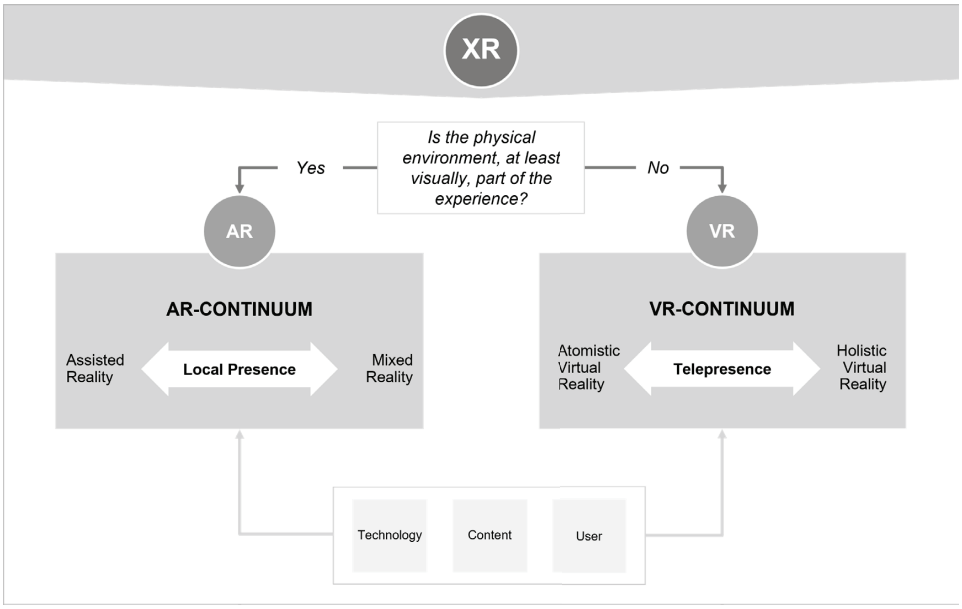

Figure 3. XR framework (Rauschnabel et al., 2022)

Especially in the last years, XR gets great attention since companies such as Meta Platforms (former Facebook), Microsoft and Apple are heavily investing in technologies such as Augmented Reality, Virtual Reality, and Mixed Reality (based on Boston Consulting Group, 2022). This fact shows the relevance and potential of theses

technologies in our (near) future. However, especially considering the profession of design, the potential of XR technologies and especially VR is unclear yet. Thus, in the present paper, based on a review of literature in the domain of design practice and design research, the potential utilization of Virtual Reality will be assessed.

3. APPROACH

The methodology for the literature review is inspired by the model for integrative reviews of Snyder (2019) and Torraco (2005). Different research data bases such as scopus and google scholar were used in order to derive suitable literature. Inclusion criteria consisted of English language as well as the inclusion of the terms “design practice”, “design research”, “virtual reality” and further terms such as “co-creation”, “human-centred design”, and “design method”. Moreover, terms related to design activities, such as “ideation”, “prototyping”, “evaluating”, “design review” and “presentation” were included in the review. Criteria were defined in order to exclude literature not suitable for the present endeavour. The exclusion criteria included alternative definitions of the term “design” as well as the absence of a designerly nature of the publication (based on Cross, 2006). Overall 28 studies were included into the review. Based on the reviewed literature, core findings of using Virtual Reality in design research and practice are shared.

4. Findings

The findings are categorized in the activities that designers carry out during the design process and consist of problem identification, creative ideation, co-creation, prototyping, evaluation, as well as presentations and design reviews.

4.1 Virtual Reality for problem identification

There is a range of methods for identifying problems for existing products/systems, including interviews, questionnaires but also usability tests, heuristic evaluations, and cognitive walkthroughs. Especially for the identification of problems involving products with digital aspects, VR has already been utilized. Carlsson & Sonesson (2017) conducted VR user tests in the field of UX for automotive cockpits to evaluate UI concepts but also identify UI flaws/problems. The results indicate great advantages in the usage of VR due to its immersive and engaging experiences that could be visualized without physical prototypes. However, especially for problem identification activities in design research and design practice, literature is sparse, indicating that further research is needed to assess

the impact that the technology of Virtual Reality can have on this specific design activity (based on Stadler, 2021).

4.2 Virtual Reality for creative ideation

Researchers already utilized Virtual Reality for creative activities such as brainstorming, creative three-dimensional sketching, designing moodboards, and conducting ideation workshops (Hamurcu et al., 2020; Israel et al., 2009). Rieuf & Bouchard (2017) developed a tool for designers in VR for creative sketching and the development of moodbards, two essential activities/methods during the development of design concepts. The researchers' findings suggest that VR in early stages of the design process can enhance emotional components of design activities and can lead to increased commitment of the involved designers regarding the task at hand. This also includes advantages related to VR such as experiencing 1:1 scales of 3D models and sketches, the ability to experience concepts out of various perspectives, as well as intuitive and natural interaction with the digital content. These results confirm implications drawn by Keeley (2018), who investigated sketching activities in Virtual Reality. The researcher also concludes that the technology allowed a greater sense of scales and perspectives when using VR.

Fromm et al. (2020) conducted a qualitative study consisting of VR brainstorming sessions in order to investigate the impact that the technology can have on negative group effects. The results show advantages of using VR for brainstorming sessions in terms of increased focus on the task as well as offering a relaxing digital environment to express ideas freely which led to a positive influence on idea generation. Another advantage of using VR in this context was the possibility to support geographically dispersed teams during the idea generation process.

4.3 Virtual Reality in co-creation

Current trends in designerly research and practices shift from company-centred activities towards user-centred approaches (Prahalad & Ramaswamy, 2004). Thus, instead of creating products for users designers increasingly design with users, resulting in advantages such as thorough understanding of user needs, increased efficiency as well as the establishment of synergies between users and designers (Prahalad & Ramaswamy, 2004).

In a co-creative design research study, researchers found out that by using VR, motivation and engagement of people was fostered. Furthermore, the technology of VR

was advantageous over conventional methods in terms of feasibility of visualizing design concepts, and efficiency in terms of time and cost. Beyond that due to the usage of VR the roles of the involved designers shifted from being creators towards being coordinators and facilitators who helped people to express themselves and their needs (Stadler, Cornet, & Frenkler, 2020a). Furthermore, Bruno & Muzzupappa (2010) propose a participatory design approach for evaluating usability in the context of house appliances by allowing virtual interaction between the product and users in a virtual environment. The researchers conclude that VR is "[…] the best tool for satisfying the needs of a participatory design approach […]" that the usage of VR allows users to suggest interesting usability improvements during the design activity.

4.4 Virtual Reality for prototyping

Especially in the field of protoyping for hardware products, VR has already been utilized as an enhancements and sometimes even as a replacement for conventional Computer-Aided Design (CAD) applications such as Rhinoceros (2019) and 3ds Max (Autodesk, 2022). A range of researchers already investigated the impact of CAD and VR within the design process (Akca, 2017; Deb et al., 2017; Freeman et al., 2017; Stadler, Cornet, Mazeas, et al., 2020; Stark et al., 2010). The investigations indicate that the major advantages relate to the visualization and experience of 1:1 scales, realistic environments, engagement, and immersion. The major drawbacks of the technology of VR involve missing accuracy in the development of high-fidelity prototypes, restricted field of view, and the absence of haptic feedback (Berg & Vance, 2016; Bishop et al., 2001; Stadler, Cornet, Mazeas, et al., 2020).

By comparing commercially available CAD applications (desktop-based) with immersive applications for the creation of splines and volumes (VR), researchers found out that VR-based applications foster increased sense of scale, enhanced perspective when experiencing the volume models, as well as increased usability. Moreover, the usage of VR for the creation of volume models supported excitement and engagement while designing (based on Stadler, Cornet, Mazeas, et al., 2020).

4.5 Virtual Reality for evaluation

In order to evaluate design concepts, products or systems, VR has already been utilized as well, including methods such as usability testing, experience simulations, and user tests (Kumar, 2012; Martin & Hanington, 2012; Stadler, 2021; van Boeijen et al., 2014). Especially in application domains, in which physical prototyping is time-consuming and

expensive, VR applications are frequently used for evaluating design concepts and design iterations.

Especially in the field of autonomous mobility, VR has been used in this context. In a range of studies, VR simulators were developed to evaluate communication concepts between autonomous vehicles and vulnerable road users such as pedestrians especially in ambiguous traffic situations such as at zebra crossings (Deb et al., 2017; Pillai, 2017; Stadler, Cornet, & Frenkler, 2019; Stadler, Cornet, Novaes Theoto, et al., 2019). In the domain of architecture, VR has been used. Kuliga et al. (2015) investigated the congruence in user experience between a real building and its digital twin. The researchers conclude that there are no significant differences in terms of user experience inside the real building and the immersive simulation, implying the suitability of using VR for such purposes.

4.6 Virtual Reality for design reviews and presentations

Due to its visualization potential, VR has already been used as a presentation and review tool of design concepts and products. Felip et al. (2020) compared product attributes of furniture presented in a real setting as well as in VR and investigated differences as well as equivalences. The researchers conclude that certain product attributes were better rated when being experienced in Virtual Reality, indicating the capabilities and potential advantages of using Virtual Reality for presentations and reviews.

Castronovo et al. (2013) evaluated immersive Virtual Reality systems for design reviews. The researcher conclude that aspects such as immersion and overall value of the VR system was rated high by the reviewers and that the usage of the technology for the design review allow users to interact with the virtual environment and its included objects in full scale and in a very intuitive way. In a patents and literature review, de Freitas et al. (2022) found out that VR is beneficial for design reviews and usability testings due to its enhanced capabilities to experience perspectives that stimulate insights, increased team engagement, improved and intuitive interactions, cost- and time- efficiency (especially for re-designs), but also increased safety for participants. Idenfitied limitations of using the technology for design reviews involved limited realism, latency issues, and communication challenges between the team members.

5. LIMITATIONS

The current investigation also involves a set of limitations. Firstly, a non-exhaustive selection of literature was reviewed and included in the study, preventing the derivation of robust results and generalizeability. Secondly, only few application domains for design

activities were covered in the present study further limiting the generalization of the results.

6. CONCLUSION

In conclusion, the present literature review gives a small insight in potential usages that Virtual Reality offers for designers in design practice and design research, especially for activities such as problem identification, co-creation, prototyping, evaluation, as well as design reviews and presentations. As the review shows, the advantages of using Virtual Reality for design research and practice mostly lie in its capabilities to immersively visualize digital information which fosters motivation, engagement as well as understanding the products to be developed. Nevertheless, the utilization of using Virtual Reality in design also involves a set of limitations mostly related to technical disadvantages such as restricted field of view, limited resolution but also the absence of haptic feedback. Still, as long as these limitations are carefully considered and covered, VR has the potential to enhance a range of activities during the design process. Furthermore, as the technology of Virtual Reality matures, new application possibilities emerge for designers, implying that VR could become the next disruptive game changer for designerly activities. Future work will involve an extended literature review for using VR in design research and practice covering further application domains for designers.

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