Towards Design Principles for Experimental Simulations in Virtual Reality – Learning from Driving Simulators

Jannes Heinrich Diedrich Menck
University of Göttingen
jannes.menck@uni-goettingen.de

Henrik Lechte
University of Göttingen
henrik.lechte@uni-goettingen.de

Tim-Benjamin Lembcke
University of Göttingen
tim-benjamin.lembcke@uni-goettingen.de

Alfred Benedikt Brendel
Technische Universität Dresden
alfred_benedikt.brendel@tu-dresden.de

Lutz M. Kolbe
University of Göttingen
lutz.kolbe@wiwi.uni-goettingen.de

Abstract

Experiments play an important role in Information Systems research. In this area, Virtual Reality (VR) technologies can serve as a tool for enabling and conducting research. e.g., to investigate human behavior in specific situations. A prime example is VR-supported driving simulators that allow researchers in the automotive domain to gather knowledge while reducing cost and complexity compared to field studies with real cars. We argue that the use of carefully designed VR-supported experiments might allow researchers to get deeper insights into human behavior. Thus, we derive design principles for VR Experiments as an artifact from the literature about VR-supported driving simulations that have been accepted as a useful tool for research in their domain.

Keywords: Virtual Reality, Simulation, Design Principles, Experiment.

1. Introduction

Virtual reality (VR) is gaining increasing importance with the advent of the Metaverse, a virtual parallel word (Lee et al., 2021). Supported by improving hardware like VR headsets such as the Oculus Quest 2, VR is available to more and more researchers. Researchers' interest in VR has grown over the years (Wohlgenannt et al., 2020), with research areas ranging from clinical applications (Garrett et al., 2018) to educational use (Radianti et al., 2020). Safety-related topics are another exemplary research area in which VR appears to be a promising tool for conducting research (Duarte et al., 2010). This applies, among other things, to safety training, research into dangerous situations such as behavior during natural disasters, and research into safety-critical warnings. In the area of warnings, conventional, physical simulators and simulation software have long been used to avoid exposing research subjects to dangerous, real-life situations and simplify the research process (Duarte et al., 2010). In the light of new, specialized hardware and improving computational power (Lee et al., 2021), VR comes as a natural extension of these traditional approaches by potentially leading to more realistic simulations (Bozkir et al., 2019). Nevertheless, VR may also have its own challenges stemming from potentially more complex hardware and less existing research and experience. This paper aims to investigate VR Experiments (VREs) as a particular use case for VR technologies. Since conducting experimental research on driving through simulation software is a long-standing research approach (Kaptein et al., 1996), we argue that the knowledge gathered from VR-based research work can be transferred to other domains like Information Systems (IS). As with driving simulations, a focal point of utilizing simulators lies in the transferability of results and learned behavior to reality (Duarte et al., 2010). Experimental research aims to answer a specific research question with the results of an experiment (Karahanna et al., 2018). Nevertheless, there might be a lack of realism and thus low external validity (Karahanna et al., 2018). VR might become an essential and promising tool for researchers (Duarte et al., 2010) by reducing cost and effort while creating credible situations (Bozkir et al., 2019). Research work that considers various safety aspects associated with automotive systems can specifically benefit VR because hazards can be represented credibly, and the tasks can also be simulated to the greatest extent possible.

URI: https://hdl.handle.net/10125/102791
978-0-9981331-6-4

In this paper, we address employing VREs for experimental research in IS from a design science perspective. The credible representations of real-world situations VREs provide make them particularly suitable for experimental research that seeks to combine the use of IS with physical or emotional aspects. Additionally, we consider the researcher's perspective on using VREs when conducting research and not only the perspective of a study participant. Thus, the results will be more useful for future research with VREs. The need for realistic VREs that enable researchers to get transferable insights leads us to the following research question:

RQ: How should VR-supported experiments be designed to provide highly transferable results in IS research?

We aim to answer this research question by conducting a design science research (DSR) approach based on Hevner et al. (2004). By first providing a comprehensive literature review based on Webster and Watson (2002) and vom Brocke et al. (2009) in section 2, we describe our methodology. Section 3 proposes eight design requirements and synthesized design principles following Gregor et al. (2020) by considering the researcher's, the simulation developer's, and the research subject's perspectives. We aim to guide future research and offer valuable suggestions on how research with VREs can be more comparable and transferable to reality by focusing mainly on the challenges and limitations of the reviewed literature and deriving design principles to guide developers of VREs.

2. Methodology and research design

Following a design science approach (Hevner, 2007), we aim to generalize and transfer the well-developed and accepted knowledge base from driving simulation VREs to VREs in IS. For a more focused research process, we chose to limit our search to driving VREs considering in-car warnings e.g., collision warnings, since the research on warnings considers both the performance and behavior of study participants. Table 1 shows our design science research (DSR) process. The three cycles (relevance, rigor, and design) are described in the work of Hevner (2007). The relevance cycle initiates a design science approach by finding an application context that provides requirements and acceptance criteria for later evaluation of the artifact to be designed. The rigor cycle ensures scientific rigor by drawing from the existing scientific knowledge base and thus ensuring the contribution of the created artifact. In the design cycle the artifact is created (or, in case of more iterations, iterated) based on the gathered knowledge from previous cycles. Lastly, the artifact is evaluated against the requirements originating from earlier cycles (Hevner, 2007). In our case, the artifact are the derived design principles with their testable propositions. Design principles are prescriptive design knowledge that aims to guide developers in creating artifacts in a specific context (Jones & Gregor, 2007). They should consist of an actor (e.g., an implementer) that wants to achieve an aim in a context. The design principles present a mechanism to achieve this aim and a rationale as a justification (Jones & Gregor, 2007).

In the relevance cycle, we performed an extensive systematic literature review on warning-related VREs for driving simulations (vom Brocke et al., 2009; Webster & Watson, 2002) shown in Table 2. After analyzing the identified relevant literature, we found the main requirements for this kind of VREs. We further found that existing simulations were rarely reused in other experiments. This leads to a problem of comparability since different simulators lead to hardly comparable results. Especially in IS research the replication of experiments is vital to ensure the validity of single studies (Jarvenpaa et al., 1985). As a second step, we performed the rigor cycle to identify knowledge relevant for developing VREs. We formulated transferred generalized requirements for VREs based on a thorough literature review and additional literature. In the design cycle, we used the requirements, the identified actors, and additional literature to find design principles for VREs as software artifacts using the framework by (Gregor et al., 2020). As suggested by Gregor et al. (2020), we mainly focus on "people aspects" in principles. Lastly, we derive testable propositions for the principles and evaluate the principles and testable propositions with researchers in a workshop.

Table 1 Design Science Research Process

	Relevance Cycle	Rigor Cycle	Design Cycle
Inputs	• Warning simulator literature	• Literature reviews	• Simulator literature • Researchers
Methods	• Literature review	• Content analysis	• Workshop with researchers
Steps	• Search Literature • Analyze publications	• Analyze publications • Identify input knowledge for design process	• Derive design principles • Evaluate design principles
Results	• Identification of problems with existing simulators	• Simulator literature • Requirements on VRES	• Evaluated design principles

To assess the current state of VREs and identify their most important features, we conducted a systematic literature review (vom Brocke et al., 2009; Webster & Watson, 2002). VR simulators and in-car warning research are highly interdisciplinary areas with technical, qualitative, and quantitative approaches. Therefore, we decided to consider the following databases: Web of Science, ACM, IEEE Xplore, Association for Information Systems, and Science Direct. An initial search was conducted with the search string:

("Virtual Reality" OR VR) AND (warn AND driv*).*

The query resulted in 426 results. After an initial title and/or abstract screening, 43 articles were considered for full-text screening. As inclusion criteria, we choose that an immersive VR-Device (Head-Mounted-Display (HMD) or a Cave Automatic Virtual Environment (CAVE)) must be used and a warning must be emitted to study participants. The search with the strings "warn*" and "driv*" yielded many articles with little relevance because "driven" and "warned" are frequently used in other contexts. Furthermore, some articles claimed to use VR but utilized neither an HMD nor a CAVE and thus, did not create a 3D representation of a situation. Nevertheless, we chose the search strings to include any relevant work. After the full-text screening, we identified 14 articles for review. A forward and backward search yielded no additional results. Lastly, we considered articles from already existing reviews on similar topics (Riegler et al., 2021; Vankov & Jankovszky, 2021), but the identified relevant articles were already included in our review. One of the fourteen articles described the implementation of a specific simulator, and three articles experimented with a named simulator. Nine articles created or customized a simulator for their experiment. Lastly, one article mentioned using a VR-Simulator; however, the simulator is not further described. Table 2 illustrates the identified literature with mentioned features or requirements for the simulators.

3. Results

3.1 Identification of literature-based requirements

We found eight requirements (R1...R8) in the literature review and grouped them into three categories shown in the concept matrix (Table 2) (Webster & Watson, 2002). The first category is immersion. It includes requirements necessary for the natural behavior of the study participant thus inducing external validity. Immersion aims to place the study participants in a virtual situation so that they are no longer fully aware of being in a simulation (Bowmann & McMahan, 2007). Presence as the human reaction to immersion is the main requirement (R1 Presence) (Schuemie et al., 2001; Slater, 2003). Presence describes a feeling of being and acting in the simulated environment and can be measured by standardized questionnaires (Schwind et al., 2019). The reviewed literature suggests and uses mainly a hand or body representation to create a sense of presence, e.g., (Riegler et al., 2019a). Moreover, the experimental situation must be presented in a way that is perceived as such and taken seriously (R2 Situation Representation) (Kinateder et al., 2012). The same applies to a possible experimental treatment. In the case of warnings, even if a multimodal warning is investigated, all components of it (e.g., audio or vibration) must be able to be experienced in the virtual world (Duarte et al., 2010; Riegler et al., 2019a).

The second category, data collection, summarizes what data the simulator should track during an experiment. This category is particularly important for the comprehensibility of the results and comparability with other studies. In the case of driving VREs, first, the movements of the controlled vehicle must be recorded (R3 Virtual Car) (Wang et al., 2014). Here, either extensive gyroscopic data (Wang et al., 2014) or only events of importance for the study (such as braking and steering) (Song et al., 2018) can be recorded with timestamps. This requirement can be generalized with the tracking of the situation. It should be constructible from the data about when participants experienced specific events and how they reacted. Second, data from study participants are needed for a comprehensive evaluation (R4 Study Participant). The reviewed studies used eye-tracking (Bozkir et al., 2019), heart rate (Uijong et al., 2019), and galvanic skin response (Morra et al., 2019) as data from the participants. A simulator should have an interface for this kind of data to align them to in-simulation events. Third, the participants' task performance needs to be tracked (R5 Task). The reviewed studies used different tasks like following a course to create a more realistic driving situation (Ma et al., 2021) or to measure the influence of warnings on task performance (Riegler et al., 2020). Task performance for both scenarios should be tracked for later comparisons with different studies.

The third category, platform, includes technical aspects of the simulator. Most importantly, the created simulation should be presented to the study participant. To achieve this, the VR-Device (R6 VR-Device) and the used (game-) engine (R7 Engine) should be state-of-the-art. The reviewed literature mainly used the HTC VIVE and the Oculus Rift as headsets. In 12 of the 14 reviewed articles, Unity3D was used as the game engine. Lastly, the simulator should support additional hardware (R8 Additional Hardware) like a steering wheel and pedals. In the case of IS experiments, it might make sense to include additional hardware if the VRE is dealing with a specific interaction device (e.g., joystick). Nevertheless, most IS experiments might not need additional hardware.

Table 2 Literature Review

	Immersion		**Data Collection**			**Platform**		
Requirements	Presence (R1)	Situation (R2)	Car (R3)	Study Participant (R4)	Task (R5)	VR Device (R6)	Engine (R7)	Additional Hardware (R8)
(Wang et al., 2014)		X	X	X	X	X		X
(Kinateder et al., 2012)		X	X	X	X	X	X	X
(Ju et al., 2019)	X	X	X		X	X	X	X
(Riegler et al., 2019a)	X	X		X	X	X	X	X
(Bozkir et al., 2019)		X	X	X		X	X	X
(Hock et al., 2016)		X			X	X	X	X
(Riegler et al., 2019b)		X			X	X	X	X
(Riegler et al., 2020)		X				X	X	X
(Colley et al., 2021)		X				X	X	X
(Ma et al., 2021)		X	X	X	X	X	X	X
(Morra et al., 2019)	X	X		X		X	X	X
(Uijong et al., 2019)		X		X	X	X	X	X
(Song et al., 2018)	X	X	X		X	X	X	X
(Charissis & Naef, 2007)			X		X	X	X	X

3.2 Derivation of design principles

After deriving and structuring the general requirements from the literature, we defined the actors by following Hevner et al. (2004). Gregor et al. (2020) suggest defining an implementer, a user, and a theorizer for the development of design principles.

The implementer is the simulation developer, who should apply the design principles to the concrete simulator. Users are the study conductors who want to use the simulator for their studies and experiments. For this purpose, the conductor will need study participants who are the enactors. The theorizer is the warning researcher who wants to capture the simulators' design knowledge. Based on the identified actors and requirements, we can now derive design principles following Gregor and Jones (2007) by adding additional insights from the literature. The relation between requirements and principles is shown in Figure 1.

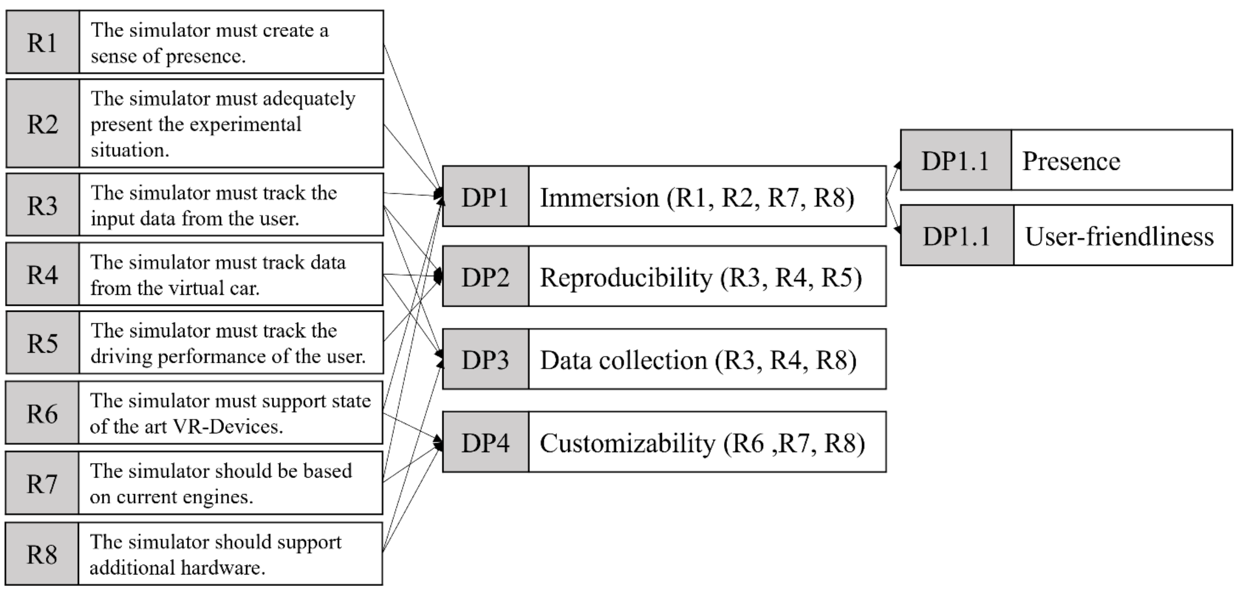

Figure 1 Design requirements and derived design principles

DP1 (Principle of Immersion) is based on the requirements R1, R2, R6, and R7. The literature shows that immersion is one of the key factors for transferable results (Bowmann & McMahan, 2007; Duarte et al., 2010). Immersion can be defined as the extent to which subjects feel they are cut off from the real world and feel motivated, or caught up, by the virtual environment as if it were real (Duarte et al., 2010). To present the virtual environment in the most realistic way, state-of-the-art VR engines and headsets should be used for the experiment.

For simulation developers to allow conductors to collect real-world, transferable data of the study participants in the simulated environment, there should be a certain amount of immersion because immersed participants are expected to behave more naturally and take hazards more seriously.

Following Gregor et al. (2020), this design principle can be decomposed into two design principles (DP1.1 and DP1.2) focusing on the study participant.

(DP1.1) Principle of Presence: *For simulation developers to allow participants to immerse as much as possible in the simulated environment, there should be a certain amount of presence because presence leads to real-world-like reactions.*

(DP1.2) Principle of User-friendliness: *For simulation developers to allow participants to immerse themselves as much as possible in the simulated environment, the simulator should be as user-friendly as possible because a user that is instantly familiar with the presented scenario is expected to act more naturally.*

DP1.1 and DP1.2 aim to immerse the participant in the given situation. Presence as the "feeling of being there" is a human reaction to immersion (Slater, 2003). It can be increased by a simulated body. Some of the reviewed simulators used virtual hands (Morra et al., 2019) or more body parts (Riegler et al., 2019a). In some situations, a self-created avatar might lead to an even higher level of presence (Dechant et al., 2021). User-friendliness can be achieved by designing an intuitive way of interacting with the simulation (Uijong et al., 2019). In the case of driving VREs, a steering wheel and pedals are the most intuitive way of controlling a virtual car. In the case of IS experiments, it should be considered to focus on a realistic simulation of the interaction with the system in the scope of the experiment. The goal of a developer should be to create an experience that feels as close to real-world scenarios as possible. We recommend that simulation developers include several questionnaires in an iterative development process – presence (Schwind et al., 2019), user Experience (UEQ) (Laugwitz et al., 2006; Schrepp et al., 2017), and simulator sickness questionnaire (SSQ) (Kennedy et al., 1993). Although all reviewed literature conducted all questionnaires outside of a VR setting, some authors (Schwind et al., 2019) recommend implementing them in the virtual environment. We formulate the following testable proposition: **(TP1)** *If a simulator follows DP1, then it will score better results in the presence questionnaire.*

The second design principle **DP2 (Principle of Reproducibility)** is based on requirements R3, R4, and R5. Whenever an experiment is conducted, the results should be understandable for other researchers so they can run their own experiments and compare results. Thus, the simulator needs to track changes in the situation, the user's inputs, and the given treatments timely aligned to achieve reproducibility. Besides the data collection, we also recommend researchers to share their virtual environment with others for further comparability and reproducibility.

For simulation developers to allow conductors to generate meaningful data, the data should be reproducible because other researchers can only compare the results with other studies when the results are reproducible.

We thus formulate: **(TP2)** *If a simulator follows DP 2, then it will lead to more comparable results between studies.*

The third design principle **DP3 (Principle of Data Collection)** is based on requirements R3, R4, and R8. Depending on the experiment, internal and external data points are to be recorded. We define internal data as data that can be measured directly within the simulation and external data as data that needs additional hardware or interfaces for the simulation.

In our reviewed literature, we found the external data points: skin conductance level (Kinateder et al., 2012), eye tracking (Bozkir et al., 2019), heart rate (Uijong et al., 2019), and the internal data points car movement (Wang et al., 2014), participant's input (Song et al., 2018), and task performance(Riegler et al., 2019b). In implementing a VRE, all named data points should be tracked and timely aligned. The simulator should provide corresponding interfaces or a general open interface for it. Figure 2 gives an overview of exemplary internal and external data in the case of VREs in the automotive domain.

For simulation developers to allow conductors to evaluate and share their results in the best manner possible, as much data as possible should be stored during the experiment because the reasons for specific reactions might not be known beforehand.

This leads to the following testable proposition: **(TP3)** *If a simulator follows DP3, then it will record enough data for an extensive analysis.*

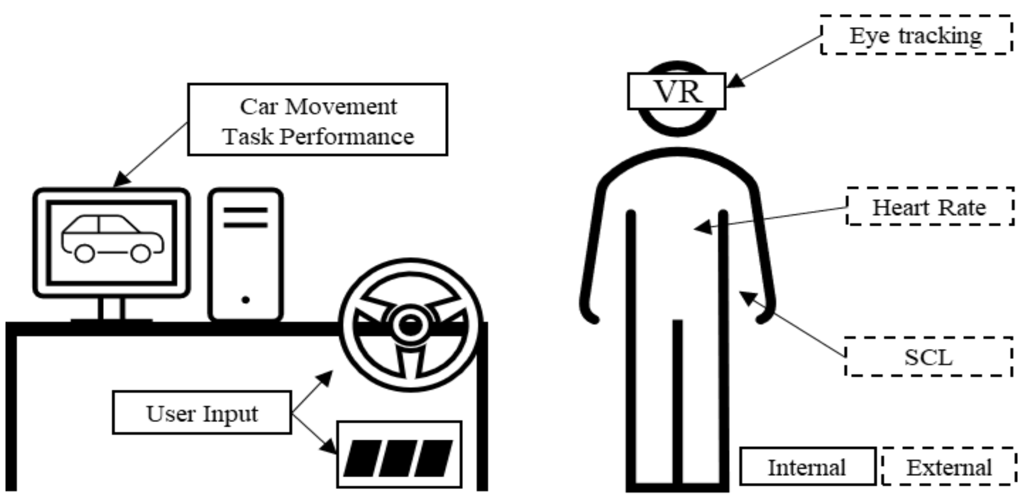

Figure 2 Internal and external data in the case of driving VREs

The fourth design principle **DP4 (Principle of Customizability)** is based on requirements R6, R7, and R8. An easily customizable simulator can create a huge research impact. Riegler et al. (2019a) present an open-source approach for a simulator with "AutoWSD" that is an example of a customizable Open-Source simulator focusing on windshield displays in different autonomous driving levels. Creating a customizable simulator should support the current state-of-the-art VR headsets and use a broadly used engine. We recommend using Unity3D as the engine because it supports all current consumer-grade VR headsets and is widely used in research. We would further recommend providing several extensively documented "Scenes" (Ready to go scenarios in Unity3D), so that even inexperienced researchers can create their own scenarios (Unity, 2022).

For simulation developers to allow conductors to perform further studies easily, there should be a certain amount of customizability because a customizable simulator increases the chances it will be reused, and a reused simulator will create highly comparable results.

We formulate the following testable proposition: **(TP4)** *If a simulator follows DP4, it will find more adoption in future warning research than extant simulators.*

Finally, we summarize the use of the presented design principles in **(TP5)**: *If a simulator follows the presented design principles, then it will be perceived as more useful by study conductors than extant simulators.*

4. Discussion

This section discusses our contribution and highlights implications for DSR, VR simulator developers, and experimental researchers that would like to use VREs. To answer our main research question: "*How should VR-supported experiments be designed to provide highly transferable results in IS research?",* we identify six DPs. In addition, we give specific recommendations and testable propositions based on existing simulators and additional literature. These allow researchers to focus on the most important attributes of a VRE. Furthermore, they motivate researchers to create reusable VREs that allow comparing studies from different experiments.

DP1 Immersion is a requirement for valid results and should motivate application designers of VREs to make use of the benefits of VR technology. DPs 1.1 and 1.2 give further guidance on how to design an application for the study participants so that they behave like they would in real life. The subsequent design principles focus on the researcher working with the VRE. DP2 (Reproducibility) and DP3 (Data collection) focus on the experimental setup to ensure useful and meaningful results of an experiment. DP4 (Customizability) emphasizes that the VRE applications should be designed in a way that allows future research in the same environment. This is one of the main benefits of VREs compared to traditional lab experiments as researchers all over the world can conduct research in the same setting without great effort.

The presented work contributes to DSR by identifying important characteristics of given solutions with the aim of optimizing VREs. In addition, we highlight relevant actors. Our research contributes to recent literature on VREs by summarizing the experience of different authors that work on or with VREs in the form of design principles and transferring them to the IS domain.

To that end, we propose recommendations on implementing VREs. IS researchers can benefit from the derived principles by incorporating them for their VREs or adapting them for similar problems. When designed carefully VREs can support science at large. The immersion and created presence can lead to valuable insights into human behavior and performance e.g., decision-making of consumers in different environments, the behavior of humans in different urban layouts, or performance in education. Like computer-simulations, (e.g. for traffic), VREs are a virtual representation of a real situation allowing researchers to measure and record data directly in the simulation and overcome constraints like cost or danger. VREs additionally include an acting human being so that actual human behavior and performance can be investigated.

5. Conclusion

VREs can play an important role in forthcoming IS research. In this paper, we introduce six design principles that help researchers use and create VREs in a more defined way by conducting a literature review about VR-supported driving simulations. The identified principles can be used to develop a VRE and focus on the ones using it. Four identified principles focus on the study conductor (immersion, reproducibility, data collection, and customizability), and two focus on the study participant (presence and user-friendliness). Using our design principles will lead to more efficient and customizable VREs that allow a broad range of researchers to reach more comparable and transferable results. We also envision that the experience of study participants is going to improve. In sum, we open the door for comparable and transferable future work with VREs in IS research.

Nevertheless, this study has some limitations. First, not all extant research on VREs has been considered in the literature analysis. However, by choosing an exemplary domain, we are confident that we were able to capture a sufficiently broad body of literature. Second, a thorough evaluation of the proposed design principles in expert interviews or an implemented VR simulator is required to verify our results. Third, within IS research, the importance of the proposed design principles may vary depending on the specific use case and research question. Lastly, it remains to be seen how practitioners can operationalize and use the design principles. Future research might develop the design principles after creating artifacts as an instance of them.

5. Acknowledgements

This work was supported by the Federal Ministry for Economic Affairs and Climate Action on the basis of a decision by the German Bundestag through project D-TRAS. This work was supported by the Austrian Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology (BMK) through project D-TRAS in the program "ICT of the Future."

References

Bowmann, D. A., & McMahan, R. P. (2007). Virtual Reality How Much Immersion Is Enough. *IEEE Computer Society*, *40*(7), 36–43. https://doi.org/10.1109/MC.2007.257

Bozkir, E., Geisler, D., & Kasneci, E. (2019, September 19). Assessment of driver attention during a safety critical situation in VR to generate VR-based training. *Proceedings - SAP 2019: ACM Conference on Applied Perception*. https://doi.org/10.1145/3343036.3343138

Charissis, V., & Naef, M. (2007). Evaluation of Prototype Automotive Head-Up Display Interface Testing Drivers Focusing Ability through a VR Simulation. *Proceedings of the 2007 IEEE Intelligent Vehicles Symposium*, 560–565.

Colley, M., Krauss, S., Lanzer, M., & Rukzio, E. (2021). How Should Automated Vehicles Communicate Critical Situations? Comparative Analysis of Visualization Concepts. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies*, *5*(3), Article 94. https://doi.org/10.1145/3478111

Dechant, M. J., Birk, M. v., Shiban, Y., Schnell, K., & Mandryk, R. L. (2021). How Avatar Customization Affects Fear in a Game-based Digital Exposure Task for Social Anxiety. *Proceedings of the ACM on Human-Computer Interaction*, *5*(CHI PLAY), Article 248. https://doi.org/10.1145/3474675

Duarte, E., Rebelo, F., & Wogalter, M. S. (2010). Virtual Reality and its potential for evaluating warning compliance. *Human Factors and Ergonomics in Manufacturing & Service Industries*, *20*(6), 526–537. https://doi.org/10.1002/hfm.20242

Garrett, B., Taverner, T., Gromala, D., Tao, G., Cordingley, E., & Sun, C. (2018). Virtual Reality Clinical Research: Promises and Challenges. *JMIR Serious Games*, *6*(4), Article e10839. https://doi.org/10.2196/10839

Gregor, S., Chandra Kruse, L., & Seidel, S. (2020). Research perspectives: The anatomy of a design principle. *Journal of the Association for Information Systems*, *21*(6), 1622–1652. https://doi.org/10.17705/1jais.00649

Hevner, A. R. (2007). A Three Cycle View of Design Science Research. *Scandinavian Journal of Information Systems*, *19*(2), 87–92.

Hevner, March, Park, & Ram. (2004). Design Science in Information Systems Research. *MIS Quarterly*, *28*(1), 75–105. https://doi.org/10.2307/25148625

Hock, P., Kraus, J., Walch, M., Lang, N., & Baumann, M. (2016). Elaborating feedback strategies for maintaining automation in highly automated driving. *AutomotiveUI 2016 - 8th International Conference on Automotive User Interfaces and Interactive Vehicular Applications, Proceedings*, 105–112. https://doi.org/10.1145/3003715.3005414

Jarvenpaa, S. L., Dickson, G. W., & DeSanctis, G. (1985). Methodological Issues in Experimental IS Research: Experiences and Recommendations. *MIS Quarterly*, *9*(2), 141–156. https://doi.org/10.2307/249115

Jones, D., & Gregor, S. (2007). The Anatomy of a Design Theory. *Journal of the Association for Information Systems*, *8*(5), 312–335. https://doi.org/10.17705/1jais.00129

Ju, U., Kang, J., & Wallraven, C. (2019). To Brake or Not to Brake? Personality Traits Predict Decision-Making in an Accident Situation. *Frontiers in Psychology*, *10*(FEB), Article 134. https://doi.org/10.3389/fpsyg.2019.00134

Kaptein, N., Theeuwes, J., & van der Horst, R. (1996). Driving Simulator Validity: Some Considerations. *Transportation Research*

Record: Journal of the Transportation Research Board, *1550*(1), 30–36. https://doi.org/10.3141/1550-05
Karahanna, E., Rai, A., Benbasat, I., & Bapna, R. (2018). Opportunities and Challenges for Different Types of Online Experiments. *MIS Quarterly*, *42*(4), iii–xi.
Kennedy, R. S., Lane, N. E., Berbaum, K. S., & Lilienthal, M. G. (1993). Simulator Sickness Questionnaire: An Enhanced Method for Quantifying Simulator Sickness. *The International Journal of Aviation Psychology*, *3*(3), 203–220. https://doi.org/10.1207/s15327108ijap0303_3
Kinateder, M., Pauli, P., Müller, M., & Mühlberger, A. (2012). Stresserleben und verändertes Fahrverhalten nach einem virtuellen Autounfall. *Zeitschrift Für Klinische Psychologie Und Psychotherapie*, *41*(3), 190–200. https://doi.org/10.1026/1616-3443/a000152
Laugwitz, B., Schrepp, M., & Held, T. (2006). Konstruktion eines Fragebogens zur Messung der User Experience von Softwareprodukten. In H. Paul & H. M. Heinecke (Eds.), *Mensch und Computer 2006* (pp. 125–134). OLDENBOURG WISSENSCHAFTSVERLAG. https://doi.org/10.1524/9783486841749.125
Lee, L.-H., Braud, T., Zhou, P., Wang, L., Xu, D., Lin, Z., Kumar, A., Bermejo, C., & Hui, P. (2021). All One Needs to Know about Metaverse: A Complete Survey on Technological Singularity, Virtual Ecosystem, and Research Agenda. *Computing Research Repository*, *14*(8). https://doi.org/10.48550/arXiv.2110.05352
Ma, X., Jia, M., Hong, Z., Kwok, A. P. K., & Yan, M. (2021). Does Augmented-Reality Head-Up Display Help? A Preliminary Study on Driving Performance through a VR-Simulated Eye Movement Analysis. *IEEE Access*, *9*, 129951–129964. https://doi.org/10.1109/ACCESS.2021.3112240
Morra, L., Lamberti, F., Gabriele Prattico, F., Rosa, S. la, & Montuschi, P. (2019). Building Trust in Autonomous Vehicles: Role of Virtual Reality Driving Simulators in HMI Design. *IEEE Transactions on Vehicular Technology*, *68*(10), 9438–9450. https://doi.org/10.1109/TVT.2019.2933601
Radianti, J., Majchrzak, T. A., Fromm, J., & Wohlgenannt, I. (2020). A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda. *Computers & Education*, *147*, Article 103778. https://doi.org/10.1016/j.compedu.2019.103778
Riegler, A., Riener, A., & Holzmann, C. (2019a). AutoWSD Virtual reality automated driving simulator for rapid HCI prototyping. *Proceedings of Mensch Und Computer 2019*, 853–857. https://doi.org/10.1145/3340764.3345366
Riegler, A., Riener, A., & Holzmann, C. (2019b). Towards dynamic positioning of text content on a windshield display for automated driving. *Proceedings of the ACM Symposium on Virtual Reality Software and Technology, VRST*, Article 94. https://doi.org/10.1145/3359996.3364757
Riegler, A., Riener, A., & Holzmann, C. (2021). A Systematic Review of Virtual Reality Applications for Automated Driving: 2009–2020. *Frontiers in Human Dynamics*, *3*, Article 689856. https://doi.org/10.3389/fhumd.2021.689856
Riegler, A., Weigl, K., Riener, A., & Holzmann, C. (2020). StickyWSD: Investigating Content Positioning on a Windshield Display for Automated Driving. *ACM International Conference Proceeding Series*, 143–151. https://doi.org/10.1145/3428361.3428405
Schrepp, M., Hinderks, A., & Thomaschewski, J. (2017). Design and Evaluation of a Short Version of the User Experience Questionnaire (UEQ-S). *International Journal of Interactive Multimedia and Artificial Intelligence*, *4*(6), 103–108. https://doi.org/10.9781/ijimai.2017.09.001
Schuemie, M. J., van der Straaten, P., Krijn, M., & van der Mast, C. A. P. G. (2001). Research on Presence in Virtual Reality: A Survey. *CyberPsychology & Behavior*, *4*(2), 183–201. https://doi.org/10.1089/109493101300117884
Schwind, V., Knierim, P., Haas, N., & Henze, N. (2019). Using Presence Questionnaires in Virtual Reality. *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*, Article 360. https://doi.org/10.1145/3290605.3300590
Slater, M. (2003). A Note on Presence Terminology. *Presence Connect*, *3*(3), 1–5.
Song, W., Pang, M., Zhao, X., & Wan, B. (2018). A Virtual Driving System Based on Customized Evaluation Model. *Proceedings - 8th International Conference on Virtual Reality and Visualization, ICVRV 2018*, 94–97. https://doi.org/10.1109/ICVRV.2018.00027

Uijong, J., Kang, J., & Wallraven, C. (2019). You or Me? Personality Traits Predict Sacrificial Decisions in an Accident Situation. *IEEE Transactions on Visualization and Computer Graphics*, *25*(5), 1898–1907. https://doi.org/10.1109/TVCG.2019.2899227

Unity. (2022). *Unity - Manual: Unity User Manual 2020.3 (LTS)*. https://docs.unity3d.com/Manual/index.html

Vankov, D., & Jankovszky, D. (2021). Effects of using headset-delivered virtual reality in road safety research: A systematic review of empirical studies. *Virtual Reality & Intelligent Hardware*, *3*(5), 351–368. https://doi.org/10.1016/j.vrih.2021.05.005

vom Brocke, J., Simons, A., Niehaves, B., Niehaves, B., & Reimer, K. (2009). Reconstructing the Giant: On the Importance of Rigor in Documenting the Literature Search Process. *ECIS 2009 Proceedings*, Article 161. https://aisel.aisnet.org/ecis2009/161

Wang, Y.-T., Huang, K.-C., Wei, C.-S., Huang, T.-Y., Ko, L.-W., Lin, C.-T., Cheng, C.-K., & Jung, T.-P. (2014). Developing an EEG-based on-line closed-loop lapse detection and mitigation system. *Frontiers in Neuroscience*, *8*(OCT), Article 321. https://doi.org/10.3389/fnins.2014.00321

Webster, J., & Watson, R. T. (2002). Analyzing the Past to Prepare for the Future: Writing a Literature Review. *MIS Quarterly*, *26*(2), xiii–xxiii. https://www.jstor.org/stable/4132319

Wohlgenannt, I., Simons, A., & Stieglitz, S. (2020). Virtual Reality. *Business and Information Systems Engineering*, *62*(5), 455–461. https://doi.org/10.1007/s12599-020-00658-9