

EXPLORING VIRTUAL REALITY APPLICATION IN CONCEPTUAL DESIGN: A PILOT EXPERIMENT WITH ENGINEERING STUDENTS

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Abstract: The development of virtual reality-based technologies brought significant change to the product design and development processes, enabling designers to visualise and interact more naturally with digital concepts in an immersive three-dimensional environment. However, despite these inherent advantages, there seems to be limited research on their integration into industrial design processes, particularly in Sub-Saharan Africa. This paper explores the application of Virtual Reality (VR) in the conceptual design process through a pilot experiment involving postgraduate and undergraduate Mechanical Engineering students. A mixed method approach is employed in this study, involving questionnaires, interviews, and observational data collected from 10 participants. Findings indicate that VR significantly enhances visualisation capabilities, increases engagement, and fosters creative design solutions, with postgraduate students adapting more quickly and demonstrating higher satisfaction. Furthermore, the findings highlight the transformative potential of immersive technologies in the learning environment, providing a roadmap for future utilisation in developing nations. Future research should focus on developing user-friendly VR applications and frameworks to help accelerate the adoption of these immersive digital technologies in design education.

Keywords: Virtual Reality, Conceptual Design, Design Education, Immersive Learning, Spatial Visualization, Mixed-Methods Research, Developing nations

1. INTRODUCTION

The recent technological advancements facilitated the growth of virtual reality technology and adoption across various industry domains, including construction, education, and retail in some developed countries like the UK and America (Bonetti et al., 2018; Lau & Lee, 2015; Wolfartsberger, 2019). The application of virtual reality (VR) technology presents a promising benefit in educational settings (Özgen et al., 2021), providing an immersive environment that may increase engagement, understanding, and retention among learners. Hence this study explores VR in an educational setting with engineering students. The aim is to evaluate to what extent VR supports conceptual design processes.

VR environments provide unique opportunities for active learning, allowing students to manipulate objects, conduct experiments, and explore scenarios in ways that are not possible in a traditional classroom setting. These applications include virtual touring of historical sites, simulation-based learning in a controlled lab setting, and engineering design education (Edwards et al., 2019; George, 2018; Joundi et al., 2020). Students who learn through VR demonstrate higher levels of motivation and interest, as compared to other conventional learning approaches (Jensen & Konradsen, 2018). However, research on the practical use in design education is still limited and this research seeks to investigate how virtual reality technology can enhance the conceptual design processes as highlighted above.

Conceptual design is often defined as an early stage in the product design and development process, which involves the generation of ideas to fulfill certain user requirements. It usually follows after the planning and task clarification stage, establishing the specific functions and constraints surrounding the design process (Cross, 1994; Kannengiesser & Gero, 2017). Conceptual designs can be represented in the form of flow charts or circuit diagrams. However, in engineering design practice where technical aspects like aesthetics need to be considered, sketches or CAD models are used to represent the visual appearance of the principal solution (Shih et al., 2017).

On the other hand, VR is an advanced stereoscopic technology, offering a more natural interaction and influencing the cognitive aspect of humans (E. K. Yang and Lee, 2020; X. Yang et al., 2018). The immersive environment is very critical in the early conceptualisation phase, where understanding spatial relationships and scale has a significant impact on the design. In conventional CAD systems, a 3D model is usually represented on a two-dimensional desktop interface whilst VR allows for three-dimensional visualisation (Horvat et al., 2019, 2022). This significantly improves a designer's spatial awareness and understanding of complex models.

Some studies have shown that immersive digital environments can stimulate creativity by allowing designers to rapidly prototype and visualise their ideas without the need to develop physical models, thereby reducing product development time and costs (Stadler et al., 2020). In addition, the incorporation of other sensory inputs such as tactile feedback provides designers with a sense of realism necessary to refine concepts and make more informed decisions (Ferrise et al., 2017; Schölkopf et al., 2021).

The remaining section of the paper is structured as follows: The next section reviews relevant literature on VR applications in industrial design education, highlighting the research gaps. This is followed by a detailed description of the research methodology,

including the participants, materials, and all procedures employed in this study. The results section presents and discusses the findings, highlighting their implications in design education. Finally, the paper concludes by outlining the key takeaways from this study.

2. LITERATURE REVIEW

2.1. Overview of VR Technology

Most studies define virtual reality (VR) as the technology that enables users to interact fully with a three-dimensional computer-simulated environment (Gigante, 1993). The birth of virtual reality technology dates back to the 1960s, with the development of the first computer-connected headsets (Brooks, 2005; Ivan, 1968). Over the past few decades, it has evolved from a futuristic concept to a practical tool used in various fields. VR systems constitute the software that generates the immersive content and hardware components for interaction and visualisation (Anthes et al., 2016). The ability of VR to simulate real-world scenarios makes it a valuable resource for educational purposes.

2.2. Previous Research on VR in Design Education

Previous research has explored the applications of VR technology in educational contexts, thus elaborating how useful VR technology is in design education by promoting a greater understanding of spatial relationships and enhancing design and creativity. To buttress this, some authors have investigated the influence of an immersive virtual environment on designers' creativity (Obeid & Demirkan, 2023; X. Yang et al., 2018). The conclusion drawn from these studies indicated a positive strong correlation between a virtual design environment and creativity attributes (attention, confidence, and motivation). In another study, students who used VR were able to produce more innovative design solutions compared to those using traditional methods such as pencil and paper sketching (Joundi et al., 2020).

Furthermore, comparative studies have been undertaken to investigate the efficacy of VR over conventional CAD tools. Learners in VR-based environments scored better performance metrics as compared to those using CAD software in 3D modeling (Banerjee et al., 2023; Feeman et al., 2018). In the context of assembly training, the CAD model is exported to the virtual environment and visual cues in the form of images or textual data are used to guide the assembly process (Dwivedi et al., 2018). Findings revealed positive feedback and performance from participants using VR as a training modality, compared to those using traditional approaches (Schwarz et al., 2020).

2.3. Theoretical Framework

The theoretical framework for this study is based on experiential learning theory, which states that learning is a process in which knowledge is formed via the transformation of experience (McCarthy, 2010). VR creates a safe learning environment in which students can actively experiment and gain actual experience, resulting in deeper learning and retention. Furthermore, Vygotsky's (1978) social constructivism theory emphasizes the importance of social interaction and collaboration in learning, which can be facilitated via shared immersive experiences.

2.4. Gaps in Existing Research

The applications of immersive digital technologies have received heightened attention, especially in the design domain. However, there is limited applicability in the initial stages of design. Previous research predominantly revolved around the visualisation of 3D CAD models in an immersive digital environment (Hawthorne et al., 2022; Horvat et al., 2022; Wolfartsberger, 2019). Our study contributes to the impact of virtual reality on conceptual design for students at different educational levels. Understanding how VR influences the conceptual design process across different educational groups can provide valuable insights towards tailoring VR-based learning experiences to meet the needs of diverse student populations in different contexts. The study also presents the pedagogical benefits of the technology and prospects for future adoption.

3. METHODOLOGY

3.1. Research Design

The main objective of this research is to investigate the overall usability and effectiveness of VR design tools in geometric modelling. In this study, a mixed-methods approach is used to explore students' experiences, which combines both quantitative and qualitative data. This notion of integrating qualitative and quantitative data in research provides a greater depth and breadth of knowledge which is not always possible when using singular approaches in isolation (Almalki, 2016). Since our study is framed around experiential learning and social constructivism, the mixed method approach provides that avenue to interact with students and construct knowledge based on their experiences and stories.

3.2. Participants

Since the study involves human participation, ethical approval was applied for and granted by the Ethics Committee at Botswana International University of Science and

Technology. It was important to attain ethics approval before we interact with human participants to address issues of informed consent and data protection amongst other things. The participants consist of two user groups: postgraduate and undergraduate students enrolled in Mechanical Engineering. Students were recruited openly by using posters displayed in the University. Interested individuals who volunteered to take part in the study were asked to review the participant information sheet and the consent form prior to the experiment. All questions raised by the participants were addressed before the experiment. Table 1 shows the demographic information of the 10 students that participated in the study.

Table 1. Demographics of participants.

Attribute	Group	Frequency	Percent (%)
Gender	Female	4	40
	Male	6	60
Age group	18-24	6	60
	25-32	4	40
Academic level	Undergraduates	5	50
	Postgraduates	5	50
CAD experience	1-2 years	3	30
	>2 years	7	70

3.3. Setup of experiment

To conduct the experiment with students, we used the Oculus Quest 2 standalone head-mounted display (HMD) VR headset, offering a screen resolution of 1832x1920 pixels per eye, and hand-held controllers. The tracking system consists of sensors, enabling 6 degrees of freedom (D.O.F) for both head and hand motion. The virtual environment was cast on an i7 CPU, 16GB RAM desktop computer, and then onto an LCD projector. The virtual tracking area measured $16m^2$, enabling participants to move more freely and interact with their design solutions, without the constraints of limited space. This area was cleared of any physical obstacles to avoid any collisions. Fig. 1 shows the schematic diagram of the setup for this experiment, adapted from (Speicher et al., 2018).

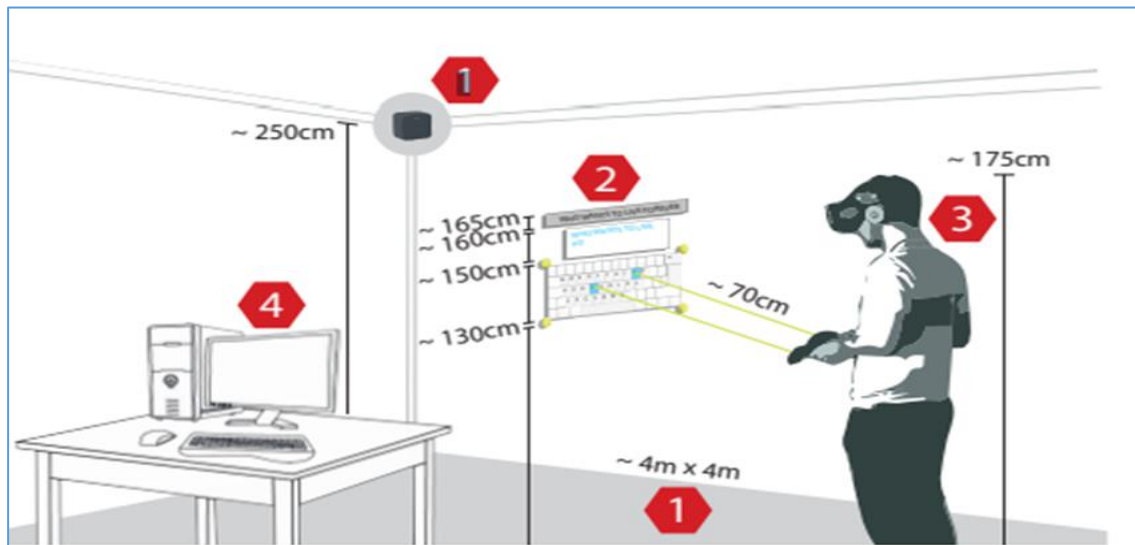


Figure 1. Setup of the VR system: (1) Optical camera at 2.5m and tracking space of $4 \times 4 \text{m}^2$; (2) Virtual environment shown on an LCD projector; (3) Participant wearing a Meta Quest VR headset and controllers; and (4) Desktop PC to capture the digital contents on the headset.

3.4. Procedure

This investigation was carried out in four main phases which are:

- Training
- Modelling
- Post-task assessment
- Data analysis

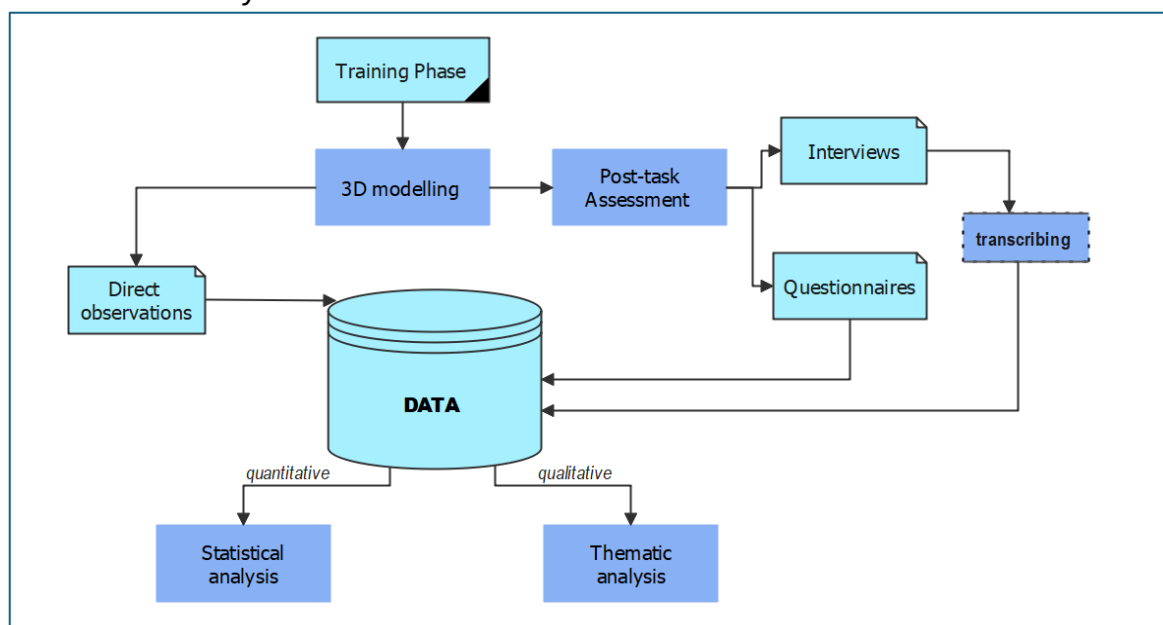


Figure 2. The experimental procedure.

3.4.1. Training phase

All the participants in this study had no prior VR experience. However, they were familiar with conventional computer-aided design (CAD) software, including AutoCAD, Solidworks, and Blender. Since the participants did not have any VR prior experience, we conducted the training sessions a week prior to the experiments. Amongst the many conceptual design software in the VR environment, we opted for the Gravity Sketch software because, in our judgement and experience, its graphical user interface has parametric adjustments and snapping features to assist novice designers in creating more accurate and detailed models than other VR design/modeling software. The other outstanding advantage is that Gravity sketch has the ability to create virtual strokes, using natural gestures without any spatial limits (Lorusso et al., 2020).

During the experimental sessions, participants explored various design features within the graphical user interface. Most students created different polygons and surfaces using the sub-divisional editing tools, enabling geometry manipulation by dragging control loops, edges, and surfaces to create more intricate designs. Fig. 3 shows some of the participants exploring the VR design interface and tools during the training phase.

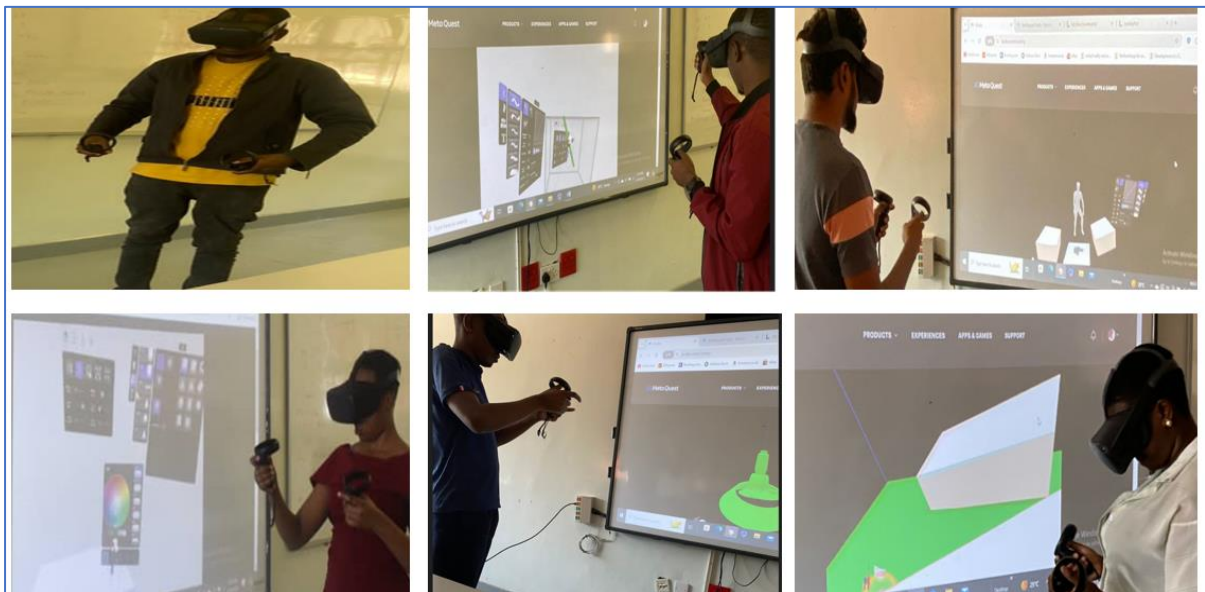


Figure 3. Participants exploring the virtual design environment.

3.4.2. 3D modelling phase

Following the training phase, the modelling phase began by asking participants to create a 3D conceptual design of a chair for either indoor or outdoor purposes. This

task was standardized across both groups to ensure comparability. Each participant was allocated a modelling time of thirty minutes. A chair was chosen for this experiment as the student designers had the capability to use digital human models, which can simulate various body postures and movements. The researchers observed the participants' interactions with the digital tools and collected data in the form of notes.

3.4.3. Post-task assessment

The participants filled out a post-intervention survey questionnaire to evaluate their individual experiences and the perceived impact of VR on design conceptualisation. The evaluation metrics included the learning curve, visualisation, and interaction capabilities. Semi-structured interviews were conducted physically, offering more in-depth insights into the students' perceptions of VR design experiences. The interviewees' responses were recorded on audio and later transcribed into text data for analysis.

3.4.4. Data analysis

The quantitative data was analysed using R 4.4.1 software, highlighting the statistical differences between the two user groups. The audio responses from the interviewees were transcribed verbatim and uploaded to NVivo 12 software for thematic analysis. Based on the insights from (Braun & Clarke, 2008), this analytic method provides a more flexible approach that investigates the various viewpoints of participants by classifying, interpreting, and reporting the themes (patterns) emerging from the data, thus leading to more concrete conclusions. Therefore, we adopted this analysis method to develop themes from the qualitative data.

4. RESULTS

4.1. Thematic analysis

Following the guidelines of an inductive approach (Chandra & Shang, 2019), the codes and relevant themes were generated from the experimental data. A visualisation of the main themes and their respective sub-themes is presented in Fig. 4.

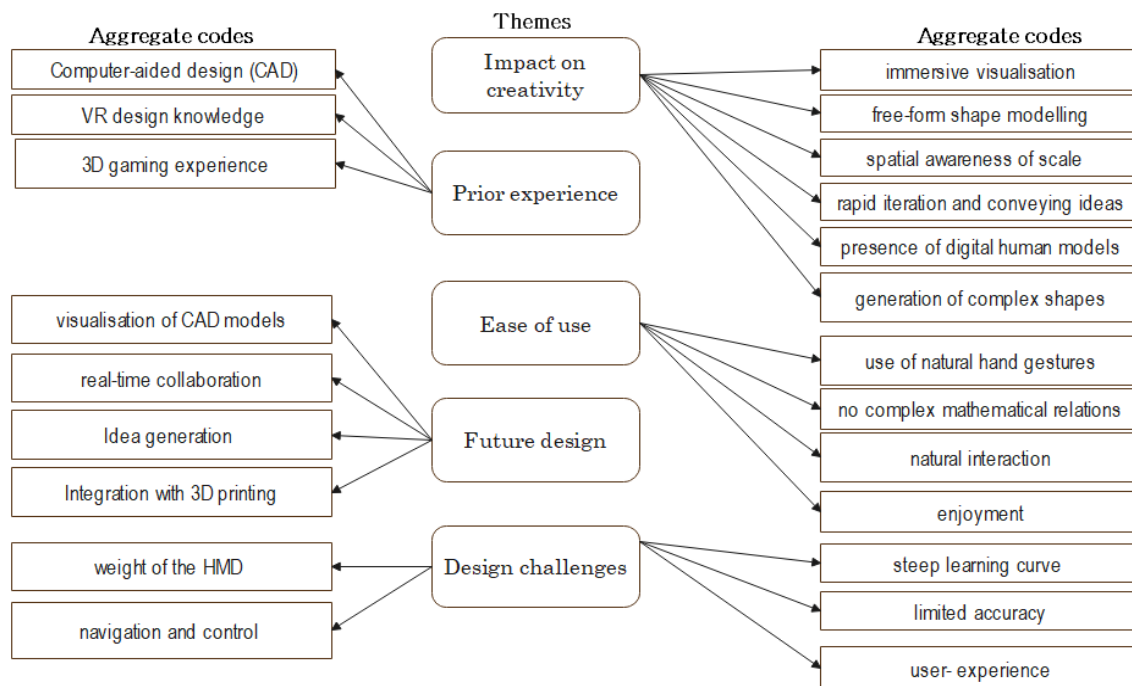


Figure 4. The main themes and sub-themes.

4.1.1. Impact on Creativity

From the analysis of the results, most participants agreed that virtual reality has a strong positive correlation with the creative design process. The chair in Fig. 5 consists of armrests, a decision influenced by the sitting posture of the digital human model (DHM) in the virtual scene. This also indicates that the use of digital models provides designers with a sense of realism, allowing them to creatively explore the products' ergonomics early in the conceptualisation phase. Thus, the conceptual design exercise has enabled participants to identify other benefits perceived by the technology, including the ability to perform free-form shape modelling without any geometric constraints and an increased sense of scale and proportion.



Figure 5. 3D chair design developed based on the sitting posture of the mannequin.

4.1.2 Prior experience

The feedback from participants also highlighted that prior computer-aided design (CAD) experience has an impact on the overall user performance in the virtual environment. All the participants had no prior VR design knowledge, however, they were able to transition to VR design, since they were already familiar with the fundamental principles and workflows of the conventional CAD systems. Some participants also revealed that the prior VR gaming experience enhanced their performance as they were able to adapt quickly to the design interface. This is supported by the following quote:

Despite my lack of familiarity with VR in design, my 3D gaming background helped me to completely understand the concept of navigating the interface (P3).

4.1.3. Ease of use

The analysis from the open-ended interview responses and direct observations gave a clear overview of the overall usability of the technology in the design context. Most responses indicated that VR enhances user interaction and engagement. The following quotes, extracted from the interview data support this statement:

I felt like I was in a real environment and was able to interact with my 3D design without any restrictions (P6).

The experience was new and exciting and I would like to explore more VR technology. Interacting in VR felt more natural and this helped me visualize the components better (P7).

However, other designers expressed their difficulty in using the VR interface. Developing complimentary design applications tailored to help novice VR designers would be a critical step toward future adoption.

Gravity Sketch is quite difficult to understand but it needs familiarization. On a scale of 1-10, I will give it a 5 (P2).

4.1.4. Future design

This theme delineates the envisioned applications of VR technology suggested by the participants. These applications include real-time collaboration, visualisation of CAD designs, idea generation, and integration with 3D printing to produce a physical model

from VR design data. This is supported by the following extracts from the interview scripts:

I wish to adopt VR in the future, perhaps integrating VR technology with 3D printing (P1).

VR is an interesting tool and I intend to integrate it with SolidWorks. After drawing in SolidWorks, I'll put it in VR and see how the object really looks at all points (P6).

I would like to use VR in the future to model objects that I'll be able to properly visualize. It seems easy to generate ideas there and have something you can build on compared to just sketching in 2D in real life (P3).

The platform supports real-time collaboration, enabling multiple users to work on the same design simultaneously. In the future, I would like to explore the design collaboration option in VR Gravity Sketch (P8).

4.1.5. Design challenges

The participants' responses and interactions also shed light on the challenges encountered during the design exercise. Most participants revealed the steep learning curve, it took some time to get acquainted with the interaction and navigation of the VR interface:

The interface of Gravity Sketch is quite different as compared to the other CAD software like Solidworks and AutoCAD which we are more familiar with. It was quite difficult and challenging to get familiarised with Gravity Sketch for the first time (P5)

In addition, one interviewee also gave feedback concerning the weight of the head-mounted display:

The VR headgear was heavy, and personally, my vision was interfered with for some time (P4).

Another challenge reported by undergraduate designers is controller usability, resulting in poor designs, as shown in Fig. 6.

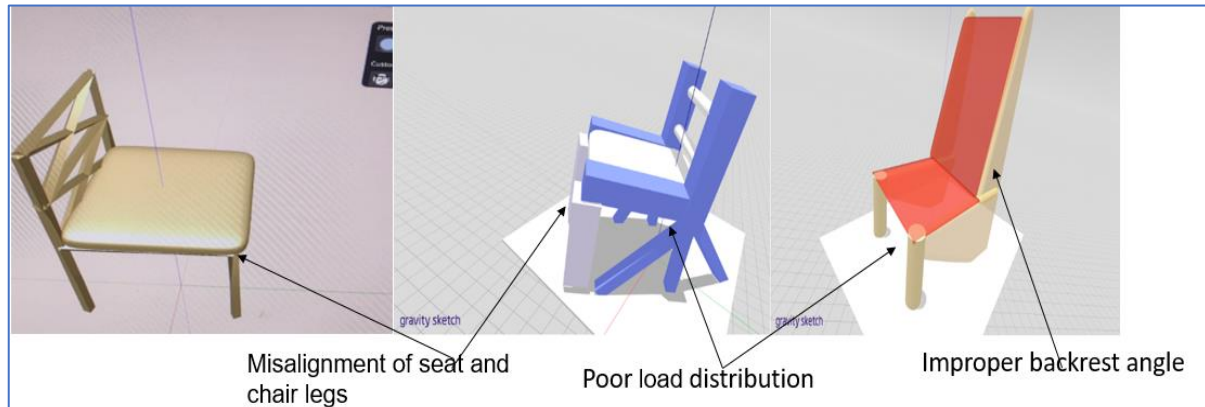


Figure 6. 3D chairs showing design defects developed by undergraduate students.

4.2. Learner's evaluation

The participants evaluated the technology's efficacy in geometric modelling on a 5-point Likert scale questionnaire, (***Scores 1: poor 2: Fair 3: good 4: good 5: very good**). All the scores are positive, asserting values between 1-5 (Joshi et al., 2015). The descriptive statistics showing the overall analysis are shown in Table 2:

Table 2. Overall analysis of each metric.

Metric	Mean	SD	Median	Min	Max	IQR
Presence	3.94	1.1322724	4	1	5	1.00
Interaction	3.68	1.0388377	4	1	5	1.00
Task performance	3.52	0.9739463	3	2	5	1.00
Learning curve	3.28	1.0887177	3	1	5	1.00
Spatial awareness	3.90	0.8864053	4	1	5	1.75
Visualization	4.28	0.7570081	4	2	5	1.00
Usability	2.82	1.0631106	3	1	4	2.00

The findings indicate that participants rated visualisation at the highest level (mean=4.28; SD=0.7570081), while the lowest is usability (mean=2.82; SD=1.0631106). The low standard deviation value on visualisation indicates that there is little variability in the participants' perceptions of this aspect. The mean value on usability is quite low and this can be attributed to the challenges faced by participants during the design process.

These descriptive statistics also reveal the higher scores on presence and interaction attributes, with mean score values of 3.94 and 3.68 respectively. Although trial sessions were conducted before the experiment, there is a need to improve the

usability and learning of VR tools and interfaces. The density plots in Fig. 7 illustrate the distribution of responses between the two user groups.

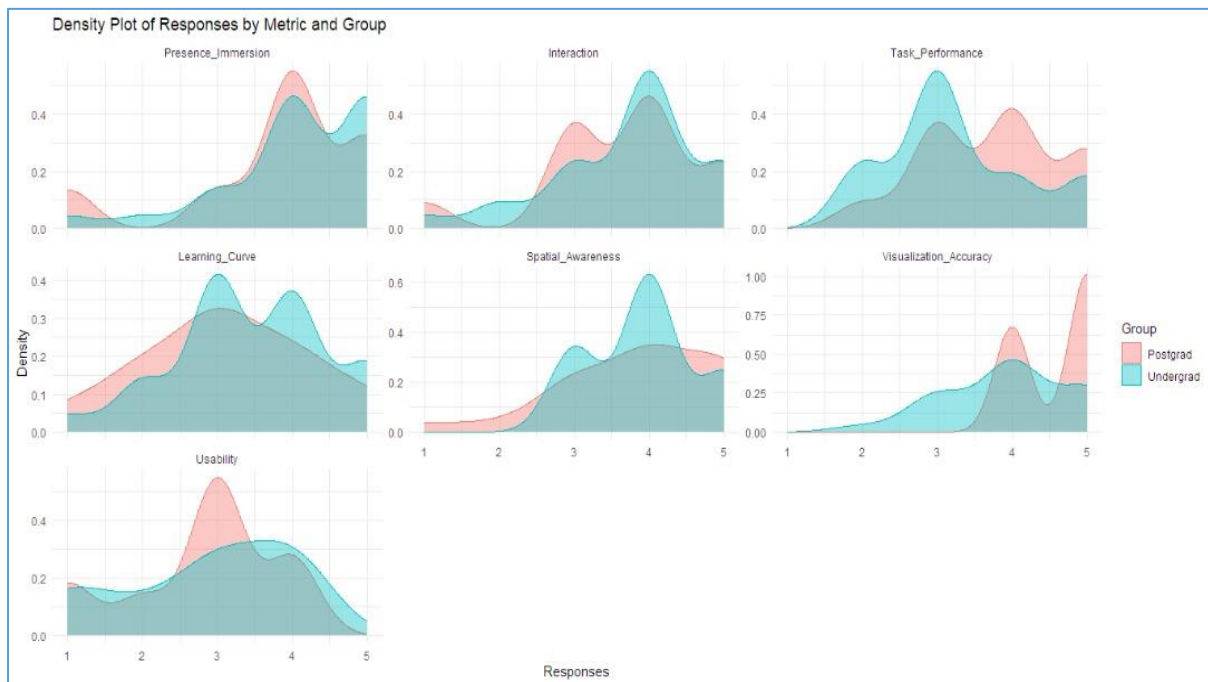


Figure. 7 density plot showing the distribution of responses between the two user groups.

On presence/immersion, postgraduates show a bimodal distribution, indicating diverse experiences, while undergraduates are more concentrated around a high score (4). This suggests that undergraduates may have a more consistent perception of presence and immersion. Both groups rate spatial awareness almost similarly, however, the plot of postgraduates' responses is more skewed to the left side with low ratings. Postgraduates rated visualisation and task performance highly (modal scores 4 and 5), while undergraduates are split between scores 3 and 5, indicating lower satisfaction. Postgraduates rated usability with a moderate score (3), while undergraduates showed a broader distribution, with notable dissatisfaction at lower scores (1-3). Addressing these usability concerns could significantly improve the experience of novice VR designers.

Undergraduates showed the highest level of satisfaction with interaction attributes. This can be attested by the prominent peaks between 4 and 5. On the learning curve aspect, postgraduates' responses show a normal distribution, which is symmetrical about the central value, while the undergraduates' responses are reflected on the multimodal curve, indicating varied opinions.

Overall, the above statistical findings indicate that postgraduates tend to have more positive and consistent ratings, particularly in metrics like presence, visualisation, and task performance while undergraduates' responses exhibit more variability in their responses, reflecting differences in familiarity, expertise, or expectations. This also suggests that postgraduates performed better in VR design than undergraduates.

4.3. VR design outcomes

All the participants used the allocated 30 minutes for the modeling experiment. Fig. 8 depicts the 3D chairs developed using VR Gravity Sketch software.

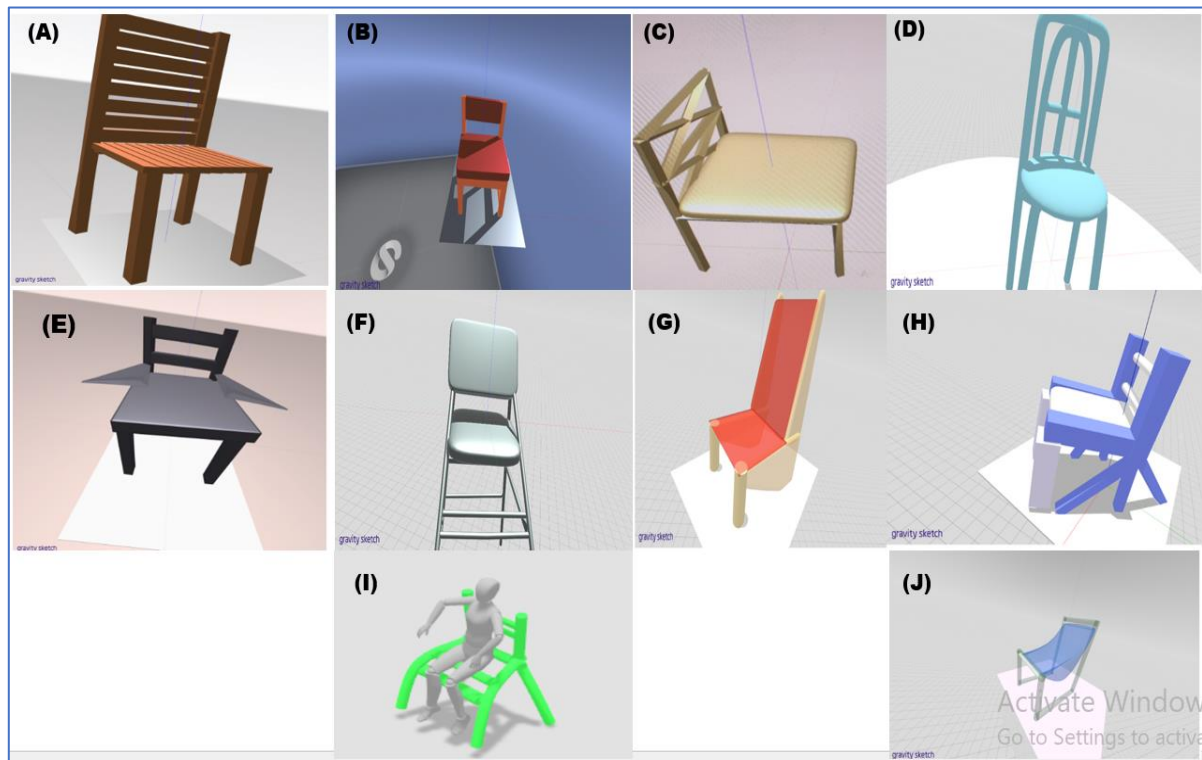


Figure 8. VR design outcomes: postgraduates (A, B, D, E, F) undergraduates (C, G, H, I, J).

The models developed by the postgraduates demonstrate their ability to adapt quickly to VR design tools and have better overall satisfaction than the other group. The sitting postures of the digital human models present in the graphical scene influenced the creative and conceptualisation process of some 3D chair models (E, G, I, and J). However, there is not much complexity and variety in all the chairs developed, as the participants chose simple designs, and they were not yet experienced with customisation options to create complex geometries. This means that prior experience is a key aspect of the VR design process.

Due to navigation and usability challenges, undergraduate models lacked precision and accuracy. Models C and H are the result of the misalignment of the seat and legs. Model G exhibits an incorrect backrest angle and a narrow base, which might cause user discomfort. Furthermore, Models C and H are unbalanced, because of poor load distribution and could potentially lead to lop-sided chairs. Some participants took several minutes of their modelling time, still deciding on the type of chair to design, and Model I is a clear reflection of unfinished work.

5. DISCUSSION

This experimental study has demonstrated the potential of virtual reality technology in the conceptual design process. The presence of an immersive virtual environment enhances design creativity (Feeman et al., 2018; Fleury et al., 2021; X. Yang et al., 2018). In our study, the presence of digital human models (DHM) in the virtual scene helped participants to explore various ideas and to be more creative as they did not have other contextual images for use as reference. This was reflected in several 3D chair designs developed based on the sitting posture of the digital human models.

Prior experience is one of the key dimensions affecting VR design. The work reported by (Banerjee et al., 2023; Berg & Vance, 2017) showed that prior CAD experience results in a more efficient workflow in VR design. All the participants had familiarity with 3D computer-aided design (CAD) and were able to transition to VR design, with those who had 3D gaming experience adapting more quickly. However, there is still a need for a deeper understanding of VR capabilities and adaptation to real-time interaction, and promote more innovative design solutions.

The inclusion of both postgraduate and undergraduate students allowed for comparative analysis. Overall, postgraduates indicated higher levels of satisfaction, as reflected by the evaluation metrics and VR design outputs. Although the majority of the participants managed to develop the 3D conceptual designs, there is a need to address the challenges surrounding usability and navigation. Our study found that students often struggled with using controllers to navigate the virtual design interface. In this regard, previous literature also agreed with our findings (Joundi et al., 2020; Laine et al., 2024). In another similar study, the VR modeling group's perceived usability mean was significantly lower than that of the traditional 3D modelling group (Banerjee et al., 2023). Addressing these challenges would enhance the overall design experience.

VR environment provides a more immersive and engaging experience, necessary for students to fully comprehend the design fundamentals. The findings suggest that the integration of VR technology into design improves students' spatial awareness of scale

and proportion. The virtual design environment has provided a realistic sense of depth and distance, participants were observed walking around frequently in space, interacting with 3D concepts. In one user-centric study, the statistical analysis revealed higher spatial perception for participants in VR than in desktop systems (Azarby & Rice, 2022).

Although VR modelling presents an engaging and interesting experience, there is a need for a detailed functional instructional set in the user interface for novice designers (Huang & Lee, 2019). For educators, this means developing curricula that integrate VR technology, providing adequate training, and addressing potential challenges, such as steep learning curves, as outlined in this study.

Exploring collaborative design through shared virtual spaces would significantly enhance user performance. In design, collaborations in various immersive environments hold the potential of aligning different team members' opinions towards a common baseline, resulting in valuable product insights. Previous research has also demonstrated how this digital technology is reshaping human-computer interactions through co-design in multi-user VR interfaces (Gong et al., 2020; Wolfartsberger et al., 2020).

5.1. Limitation of the Study

The study's sample size was relatively small, and the duration of the experiment was limited. Future research should consider increasing sample size and extended study periods to fully validate and expand upon these findings. In addition, future investigations should also focus on exploring the long-term impacts of VR applications in design education, and critically examine how the digital technology compares to conventional CAD software and its transition to the manufacturing industry, thereby promoting innovative products in the Sub-Saharan Region.

6. CONCLUSION

This study contributes significantly to the generation of theoretical knowledge of emerging design technologies. The pilot experiments demonstrate VR's potential in transforming design education, with the ability to bridge the gap between academic concepts and practical applications, offering a more hands-on approach. The immersive and interactive environment allows better visualisation, enhanced interaction, and creative design solutions.

As the technology continues to evolve, its applications within the educational context are also expected to increase. The inclusion of gamification-based techniques in the

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VR learning environment presents an interesting avenue that can be explored to foster an understanding of conceptual design education. This project provides the groundwork for future investigations into the use of immersive digital technologies in education environments, with a view to eventually expand to other significant industries within the Sub-Saharan Region.

DATA AVAILABILITY STATEMENT

The data will be made available upon request.

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DECLARATION OF INTERESTS

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

- Almalki, S. (2016). Integrating Quantitative and Qualitative Data in Mixed Methods Research—Challenges and Benefits. *Journal of Education and Learning*, 5(3), 288. <https://doi.org/10.5539/jel.v5n3p288>
- Anthes, C., García-Hernández, R. J., Wiedemann, M., & Kranzlmüller, D. (2016). State of the art of virtual reality technology. *IEEE Aerospace Conference Proceedings, 2016–June*. <https://doi.org/10.1109/AERO.2016.7500674>
- Azarby, S., & Rice, A. (2022). *Understanding the Effects of Virtual Reality System Usage on Spatial Perception : The Potential Impacts of Immersive Virtual Reality on Spatial Design Decisions*.
- Banerjee, S., Chowdhury, A., & Yein, N. (2023). *User Experience Evaluation of a Virtual Reality Tool Used for 3D Modelling in Industrial Design Education : A Study in the Indian Context*.
- Berg, L. P., & Vance, J. M. (2017). Industry use of virtual reality in product design and manufacturing: a survey. *Virtual Reality*, 21(1), 1–17. <https://doi.org/10.1007/s10055-016-0293-9>
- Bonetti, F., Warnaby, G., & Quinn, L. (2018). *Augmented Reality and Virtual Reality in Physical and Online Retailing: A Review, Synthesis and Research Agenda*. 119–132. https://doi.org/10.1007/978-3-319-64027-3_9
- Braun, V., & Clarke, V. (2008). Using thematic analysis in psychology, Qualitative Research in Psychology. *Journal of Chemical Information and Modeling*, 3(2), 77–101. <http://dx.doi.org/10.1191/1478088706qp063oa>
- Brooks, F. P. (2005). *What's Real About Virtual Reality? December*, 2–3.

- <https://doi.org/10.1109/vr.1999.756916>
- Chandra, Y., & Shang, L. (2019). Inductive Coding. *Qualitative Research Using R: A Systematic Approach*, 91–106. https://doi.org/10.1007/978-981-13-3170-1_8
- Cross, N. (1994). *Engineering Design Methods* (pp. 35–40).
- Dwivedi, P., Cline, D., Joe, C., & Etemadpour, R. (2018). Manual assembly training in virtual environments. *Proceedings - IEEE 18th International Conference on Advanced Learning Technologies, ICALT 2018*, 395–399. <https://doi.org/10.1109/ICALT.2018.00100>
- Edwards, B. I., Bielawski, K. S., Prada, R., & Cheok, A. D. (2019). Haptic virtual reality and immersive learning for enhanced organic chemistry instruction. *Virtual Reality*, 23(4), 363–373. <https://doi.org/10.1007/s10055-018-0345-4>
- Feeman, S. M., Wright, L. B., & Salmon, J. L. (2018). Exploration and evaluation of CAD modeling in virtual reality. *Computer-Aided Design and Applications*, 15(6), 892–904. <https://doi.org/10.1080/16864360.2018.1462570>
- Ferrise, F., Graziosi, S., & Bordegoni, M. (2017). Prototyping strategies for multisensory product experience engineering. *Journal of Intelligent Manufacturing*, 28(7), 1695–1707. <https://doi.org/10.1007/s10845-015-1163-0>
- Fleury, S., Blanchard, P., & Richir, S. (2021). A study of the effects of a natural virtual environment on creativity during a product design activity. *Thinking Skills and Creativity*, 40(March), 100828. <https://doi.org/10.1016/j.tsc.2021.100828>
- George, B. H. (2018). Using Virtual Tours to Facilitate Sustainable Site Visits of Historic Sites. *European Journal of Sustainable Development*, 7(4), 411–422. <https://doi.org/10.14207/ejsd.2018.v7n4p411>
- Gigante, M. A. (1993). Virtual Reality: Definitions, History and Applications. In *Virtual Reality Systems*. ACADEMIC PRESS LIMITED. <https://doi.org/10.1016/b978-0-12-227748-1.50009-3>
- Gong, L., Söderlund, H., Bogojevic, L., Chen, X., Berce, A., Fast-Berglund, Å., & Johansson, B. (2020). Interaction design for multi-user virtual reality systems: An automotive case study. *Procedia CIRP*, 93, 1259–1264. <https://doi.org/10.1016/j.procir.2020.04.036>
- Hawthorne, W., Sutton, M., Ransing, V., Mocko, G. M., Turner, C., & Walton, J. (2022). The use of virtual reality to support engineering design reviews. *Proceedings of the Ground Vehicle Systems Engineering and Technology Symposium, Opsec 6281*, 16–18. [http://gvsets.ndia-mich.org/documents/DESE/2022/The Use of Virtual Reality to Support Design Reviews.pdf](http://gvsets.ndia-mich.org/documents/DESE/2022/The%20Use%20of%20Virtual%20Reality%20to%20Support%20Design%20Reviews.pdf)
- Horvat, N., Martinec, T., Perišić, M. M., & Škec, S. (2022). Comparing design review outcomes in immersive and non-immersive collaborative virtual environments. *Procedia CIRP*, 109, 173–178. <https://doi.org/10.1016/j.procir.2022.05.232>
- Horvat, N., Škec, S., Martinec, T., Lukacevic, F., & Perišić, M. M. (2019). Comparing virtual reality and desktop interface for reviewing 3D CAD models. *Proceedings of the International Conference on Engineering Design, ICED, 2019–August*, 1923–1932. <https://doi.org/10.1017/dsi.2019.198>
- Huang, H., & Lee, C. (2019). Factors affecting usability of 3D model learning in a virtual reality environment. *Interactive Learning Environments*, 0(0), 1–14. <https://doi.org/10.1080/10494820.2019.1691605>
- Ivan, S. (1968). *Head-Mounted Three Dimensional Display*. 33(pt 1), 757–764. <https://doi.org/10.1145/1476589.1476686>
- Jensen, L., & Konradsen, F. (2018). A review of the use of virtual reality head-mounted

- displays in education and training. *Education and Information Technologies*, 23(4), 1515–1529. <https://doi.org/10.1007/s10639-017-9676-0>
- Joshi, A., Kale, S., Chandel, S., & Pal, D. (2015). Likert Scale: Explored and Explained. *British Journal of Applied Science & Technology*, 7(4), 396–403. <https://doi.org/10.9734/bjast/2015/14975>
- Joundi, J., Christiaens, Y., Saldien, J., Conradie, P., & De Marez, L. (2020). An Explorative Study towards Using VR Sketching as a tool for Ideation and Prototyping in Product Design. *Proceedings of the Design Society: DESIGN Conference*, 1, 225–234. <https://doi.org/10.1017/dsd.2020.61>
- Kannengiesser, U., & Gero, J. S. (2017). Can Pahl and Beitz' systematic approach be a predictive model of designing? *Design Science*, 3, 1–20. <https://doi.org/10.1017/dsj.2017.24>
- Laine, J., Rastas, E., Seitamaa, A., Hakkarainen, K., & Korhonen, T. (2024). Immersive virtual reality for complex skills training: content analysis of experienced challenges. *Virtual Reality*, 28(1), 1–26. <https://doi.org/10.1007/s10055-024-00955-8>
- Lau, K. W., & Lee, P. Y. (2015). The use of virtual reality for creating unusual environmental stimulation to motivate students to explore creative ideas. *Interactive Learning Environments*, 23(1), 3–18. <https://doi.org/10.1080/10494820.2012.745426>
- Lorusso, M., Rossoni, M., & Colombo, G. (2020). Conceptual modeling in product design within virtual reality environments. *Computer-Aided Design and Applications*, 18(2), 383–398. <https://doi.org/10.14733/cadaps.2021.383-398>
- McCarthy, M. (2010). Experiential Learning Theory: From Theory To Practice. *Journal of Business & Economics Research (JBER)*, 8(5), 131–140. <https://doi.org/10.19030/jber.v8i5.725>
- Obeid, S., & Demirkan, H. (2023). The influence of virtual reality on design process creativity in basic design studios. *Interactive Learning Environments*, 31(4), 1841–1859. <https://doi.org/10.1080/10494820.2020.1858116>
- Özgen, D. S., Afacan, Y., & Sürer, E. (2021). Usability of virtual reality for basic design education: a comparative study with paper-based design. *International Journal of Technology and Design Education*, 31(2), 357–377. <https://doi.org/10.1007/s10798-019-09554-0>
- Schölkopf, L., Lorenz, M., Stamer, M., Albrecht, L., Klimant, P., Hammer, N., & Tümler, J. (2021). Haptic feedback is more important than VR experience for the user experience assessment of in-car human machine interfaces. *Procedia CIRP*, 100(March), 601–606. <https://doi.org/10.1016/j.procir.2021.05.130>
- Schwarz, S., Regal, G., Kempf, M., & Schatz, R. (2020). Learning Success in Immersive Virtual Reality Training Environments: Practical Evidence from Automotive Assembly. *ACM International Conference Proceeding Series*. <https://doi.org/10.1145/3419249.3420182>
- Shih, Y. T., Sher, W. D., & Taylor, M. (2017). Using suitable design media appropriately: Understanding how designers interact with sketching and CAD modelling in design processes. *Design Studies*, 53, 47–77. <https://doi.org/10.1016/j.destud.2017.06.005>
- Speicher, M., Feit, A. M., Ziegler, P., & Krüger, A. (2018). Selection-based text entry In Virtual Reality. *Conference on Human Factors in Computing Systems - Proceedings, 2018–April*, 1–13. <https://doi.org/10.1145/3173574.3174221>

International Conference on Engineering Education and Management (IC2EM'24), September 23-25th, 2024, BIUST, Botswana

- Stadler, S., Cornet, H., Mazeas, D., Chardonnet, J. R., & Frenkler, F. (2020). IMPRO: Immersive Prototyping in Virtual Environments for Industrial Designers. *Proceedings of the Design Society: DESIGN Conference*, 1, 1375–1384. <https://doi.org/10.1017/dsd.2020.81>
- Wolfartsberger, J. (2019). Analyzing the potential of Virtual Reality for engineering design review. *Automation in Construction*, 104, 27–37. <https://doi.org/10.1016/j.autcon.2019.03.018>
- Wolfartsberger, J., Zenisek, J., & Wild, N. (2020). Supporting teamwork in industrial virtual reality applications. *Procedia Manufacturing*, 42, 2–7. <https://doi.org/10.1016/j.promfg.2020.02.016>
- Yang, E. K., & Lee, J. H. (2020). Cognitive impact of virtual reality sketching on designers' concept generation. *Digital Creativity*, 31(2), 82–97. <https://doi.org/10.1080/14626268.2020.1726964>
- Yang, X., Lin, L., Cheng, P. Y., Yang, X., Ren, Y., & Huang, Y. M. (2018). Examining creativity through a virtual reality support system. *Educational Technology Research and Development*, 66(5), 1231–1254. <https://doi.org/10.1007/s11423-018-9604-z>