INTERNATIONAL CONFERENCE ON ENGINEERING AND PRODUCT DESIGN EDUCATION
9-10 SEPTEMBER 2021, VIA DESIGN, VIA UNIVERSITY COLLEGE, HERNING, DENMARK

PROTOTYPING REMOTELY TOGETHER WITH 2D, 3D AND IMMERSIVE VIRTUAL REALITY DESIGN TOOLS

Pete EVANS[1] and Carina SÖDERLUND[2]
[1]Iowa State University, United States of America
[2]Mälardalens Högskola

ABSTRACT
The 2020 pandemic demanded changes to design education from in-person to distant and hybrid learning and accelerated the use of new technologies in both design education and professional working methods. In this new paradigm, how do we re-engage studio-like interactions, collaborative making and co-design strategies? This preliminary study, with 25 midwestern US industrial design students, adds to previous research on designing with 2D and 3D digital desktop tools versus immersive virtual reality when co-designing prototypes. The results showed a measurable difference in the quantity of prototypes favouring digital desktop design tools, but a negligible difference in the quality of prototypes even with little experience with immersive virtual reality tools. This study suggests a need to integrate immersive virtual reality in earlier design education as more experience may lead to further advantages and design results.

Keywords: Prototyping, immersive virtual reality, distant learning

1 INTRODUCTION

The COVID-19 pandemic has accelerated trends that were anticipated to take years to mere months. Directly, this is on top of the exponential trends in digital technology transformation already identified around workforce [1] and learning [2]. Due to the pandemic, online teaching and learning had to rapidly develop in different contexts, often situated at different locations at a distance which impacted studio-like in-person learning. There are studies that distance diminishes engagement between peers, instructors and also the important corporeal material in design amongst others [3, 4, 5]. As a designer, the studio environment is considered to provide a rich multi-modal engagement for communication and the making process. Preparing students to thrive in these distant interactions and then their digital advancing professional domains becomes a cornerstone for today's pedagogy.

A previous pilot on immersive virtual reality (IVR) among design students indicates the potential for divergent thinking and creativity [6] when using IVR to design. We believe it is critical to include mediated embodied experience in distant design education. Our aim is to explore when students co-design prototypes in IVR compared to other distant desktop solutions. Co-design is a collaborative way of approaching the design process, including designers and/or other relevant actors that do not have design experience in the process [7]. In this article we approach co-design as design students collaborating in the early phase of the design process, during idea generation and early prototyping.

This research sets out to answer the question, what are the differences and similarities between 2D and 3D design tools when co-designing prototypes in an immersive virtual reality collaborative environment, compared to distant desktop solutions.

This preliminary study is conducted in a university setting with about 25 industrial design students. We surveyed students' pre-knowledge about 2D, 3D and virtual reality design tools, then evaluated their co-designed prototypes and analysed their reflections on these experiences.

2 RELATED RESEARCH

The related research was sparse when searching for “product design” or “industrial design” with “design pedagogy” and “VR” (Virtual Reality). The product design string returned (37) results and the industrial design string returned (44) results.

Reviewing these returns relevant to this study narrowed the references to seven. This points to a rich area of design research and advancement in the near term, as well as methods for understanding and evaluating design in IVR and related technologies. Recent advances in consumer IVR technologies have likely contributed to this lack of research. The Oculus Rift, the first generation of consumer IVR headsets on the market was released in 2016 and still required an attached computer with a capable video card to run the IVR software. And the Oculus Quest, the first consumer IVR headset without requiring a computer with adequate graphics capability to run IVR software for design, came out in 2019.

While the existing research is sparse, it is also inspiring to see work being done with this new capability. Price, et al. [8] highlight the paradigm shift from “seeing” (more visual approach) to “feeling” (holistic, embodied respecting the sensing body) with IVR as one of the driving technologies. Mitchell, et al. [9] conclude this type of experiential instruction enhances the construction of meaning and improves applications of touch across digital (virtual) and physical design. Camba, Soler, and Contero [10] bring forward IVR as being used as a catalyst for integrated collaborative student work. The studies by Ozgen, Afacan, and Surer [11], conclude that IVR was a valid tool where the enjoyability and intention could be indicating reduced cognitive load, increased student engagement, and made learning easy, concrete and enjoyable. Gero and Milovanovic [12] connect AR or IVR with design that can technically be accomplished through Eye tracking, electrodermal activity (EDA), ECG and emotion tracking and hand tracking. The reviewed article points more toward future work in design education. Cindioğlu’s study [13] indicates beginning architecture students in mixed-reality (MR) are more responsive and less fixated in MR, where changes seemed less consequential, than in the real world. In addition to the driving pilot study by Lee, Sun, and Yang [14], these authors all connect emerging technologies such as IVR to an increased understanding in design and engineering disciplines, where students showed reduced cognitive loads and improved divergent thinking.

3 METHODS

The project goal is to explore the role of IVR in the early phase of the design process using consumer IVR headsets and software when co-designing prototypes.

The study began with an online survey Technology Familiarity Assessment (TFA). This gauged the students’ general knowledge of 2D and 3D design tools and their exposure to IVR prior to the study.

Then, twenty-five university industrial design students were divided into two main teams, A and B. Teams are determined by most diverse partnerships as possible. On the first rotation, Team A was provided IVR headsets and Rumii software and Team B used general digital desktop equivalent software, Topia for audio/video communication and Google Jamboard for co-design collaboration. Both teams were assigned the same design challenge and ideated and prototyped designs over two class sessions (40 minutes each). Pictures were captured of Team A, the IVR group, while producing each design prototype session. Team B, the NonVR group submitted PDFs of their online work during each co-design prototyping session. Both teams also submitted self-reflection documents of their co-design prototyping session. Then the teams rotated roles. Then the study was repeated and both teams were assigned a similar but new design challenge and ideated and prototyped designs over two class sessions (40 minutes each). Both teams also submitted self-reflection documents of their co-design prototyping session.

The design assignments in this study were based on principles derived from Heidi Hayes Jacobs [15] who articulates embodied learning interactions actualized in practice by Rosan Bosch Studio (2018) around metaphors of mountain top, cave, campfire, watering hole, hands-on and movement [16]. For example, one assignment revolved around the metaphor “Mountain Top.” This metaphor acted as the design brief for the students where they designed *a place to stand* and *a light*.

The prototypes made by the two teams were then evaluated. Each prototype was evaluated based on four primary aspects: 1) quantity of prototypes, 2) quality of prototypes, 3) co-design interaction and 4) novelty of solutions. Two of these aspects, the quality and novelty aspects were rated on a 10-point scale by four expert raters–instructors/professionals in design including the teacher–and then analysed, modelled on the Consensual Assessment Technique (CAT) by T. M. Amabile in 1982 where expert raters independently evaluate aspects of a product's creativity [17] similar to a sporting judge panel reviewing their sporting event.

4 RESULTS

The initial online Technology Familiarity Assessment (TFA), completed at the beginning of the study, is shown in Figure 1. There were three primary areas of assessment: (1) Students' use of 2D design tools, their favourite top three and how they rated themselves as beginner, intermediate or advanced in their use of these 2D tools; (2) Students' use of 3D design tools, their favourite top three and how they rated themselves as beginner, intermediate or advanced in their use of these 3D tools; and (3) Students' experience with IVR, how many hours they had spent in IVR, and if they owned a consumer IVR headset.

AREA OF ASSESSMENT 1					
1ST 2D tool		**2ND 2D tool**		**3RD 2D tool**	
Photoshop	7	Illustrator	4	Indesign	2
Sketchbook	1	AutoCAD	1	Adobe XD	1
Indesign	7	Procreate	2	Illustrator	5
Adobe CC	1	AAE	1	Photoshop	3
Illustrator	2	Adobe Sketch	1	Sketchbook	1
Clip Studio	1	Indesign	3		
		Photoshop	2	Advanced	0
Advanced	5	FCP	1	Intermediate	8
Intermediate	14	Keyshot	1	Beginner	6
Beginner	0			N=	14
N=	19	Advanced	2		
		Intermediate	12		
		Beginner	4		
		N=	18		

AREA OF ASSESSMENT 2					
1ST 3D tool		**2ND 3D tool**		**3RD 3D tool**	
Solidworks	16	Keyshot	8	AutoCAD	1
Keyshot	3	Fusion360	1	Shapr3D	1
		Blender	2	Inventor	1
Advanced	4	Solidworks	3	Masterpiece VR	1
Intermediate	12	PhotoView 360	1	Minecraft	1
Beginner	3	Rhino	1	Fusion3D	2
N=	19	Inventor	1	Keyshot	1
		3DS Max	1	Blender	1
		Advanced	2	Advanced	0
		Intermediate	10	Intermediate	3
		Beginner	6	Beginner	6
		N=	18	N=	9

AREA OF ASSESSMENT AREA 3			
VR Experience			
A Great Deal	1		
A moderate amount	3		
A little	10		
None at all	6		
Ownership(N=20)	2		
		HRS	**#**
Sum	214	0	6
Avg	10.7	1 to 5	9
Min	0	10 to 15	1
Max	50	20	1
Count	20	50	3
		N=	20

Figure 1. Student responses to TFA survey showing their top 2D and 3D digital design tools and IVR experiences prior to study

Figure 2 compares student responses in the first two areas of assessment, (1) Students' use of 2D design tools and (2) Students' use of 3D design tools. The figure shows students indicated a lower knowledge and experience with 3D digital design tools as compared to their knowledge and experience with 2D digital design tools. Responses in the third area of assessment about VR experience which is not shown in Figure 2 but noted in Figure 1, indicates 80% responded with "None at all" or "A little" experience with IVR technology and only 10% responded that they own their own headset.

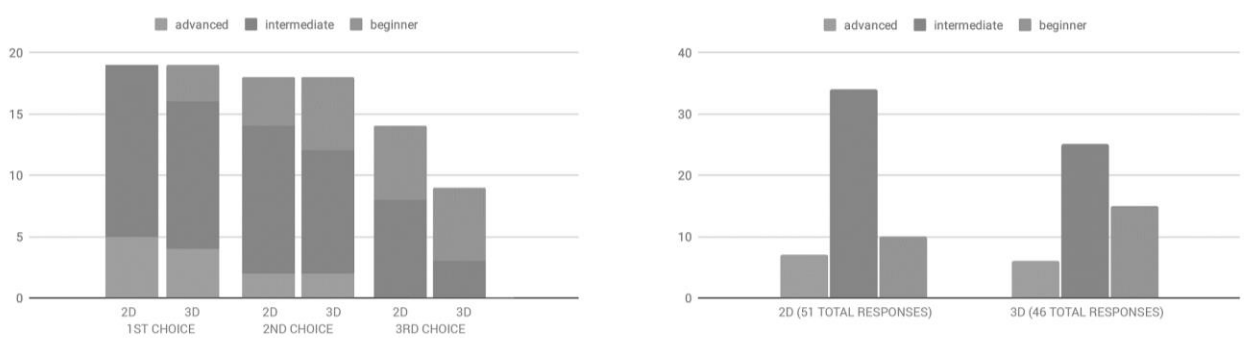

Figure 2. A comparison of the TFA data showing top 3 2D/3D digital design tools used by students (on left) and a comparison of total responses (on right). In both cases, students self-report their perceived ability with these tools

In evaluating the data, the quantity of prototypes showed a clear result favouring NonVR prototyping versus IVR prototyping. Out of a total of 50 prototypes, which were distinguished as unique ideas, 40 were NonVR prototypes. The prototypes were also evaluated to be one of four typologies: (1) low aesthetic, (2) high aesthetic, (3) low function, or (4) high function [18]. 60% of evaluations found the prototypes to be "low aesthetic" out of all for typologies. Then when comparing the aesthetic categories to the functional categories, responses showed approximately 75% of evaluations rating the prototypes "aesthetic" versus "functional." This aligns with the students in this study coming from an industrial design background versus an engineering background where functional attributes might appear more often than in industrial design.

A more nuanced evaluation of four additional aspects of the prototypes included, (1) response to the design brief, (2) appropriate use of scale, shape, colour and form as an early phase design task, (3) technical quality of the prototype, and (4) novelty. These four aspects were rated 0-10 with 0 being "worst" and 10 being "best". Across all four questions, a composite (across teams) the NonVR prototypes average scored 1.1 higher than a composite (across teams) IVR prototype. Prototype results also evaluated better (within teams) in NonVR than they did in IVR (within teams) by an average of 1.1. However, it is notable that in a sum by totalling scores across the prototypes, the highest score was a prototype completed in IVR (127) with two NonVR prototypes very close behind (121, 123). These scores indicate both modes can perform well but also indicate a negligible difference between IVR and NonVR.

The reflections around the IVR and NonVR prototyping provided individual feedback for insights into the co-design aspects and perceived benefits and shortcomings for these prototyping methods. For the IVR prototyping, there were several student comments around the challenges of the initial orientation to Rumii as software, Rumii's unique interface challenges for co-designing prototypes, and generally getting used to a virtual environment. There were also comments noting the advantages IVR co-design provided early team-oriented design work. Notably, there were comments around a more perceived embodied co-design environment permitting a more direct understanding of a teammate's actions and intentions akin to "a natural design activity" and better than translating NonVR prototyping ideas to Jamboard documents. Looking at the IVR experience in Rumii, one student wrote, "... the VR space, it felt a lot more collaborative and realistic," and another, "… really easy to visualize what she was thinking once she began drawing." And "The fully immersive environment led me to think with my hands, and the space around me." Another comment noted, "we were able to see each other in the process." The student experiences with Rumii also brought important comments about prototyping shortcomings like, "quite primitive ideation," "one (shared) main menu," and an issue where, "creations being deleted if one teammate left." For the NonVR prototyping, there were comments that NonVR prototyping did not permit the level of co-design and collaboration as IVR prototyping and that the Jamboard drawing tools were not as articulate as digital drawing normally allows. Students noted it, "lacked the ability to really sketch and draw easily," even, "ineffective for ideating" and, "not as collaborative, as we couldn't sketch together as easily as we could build together."

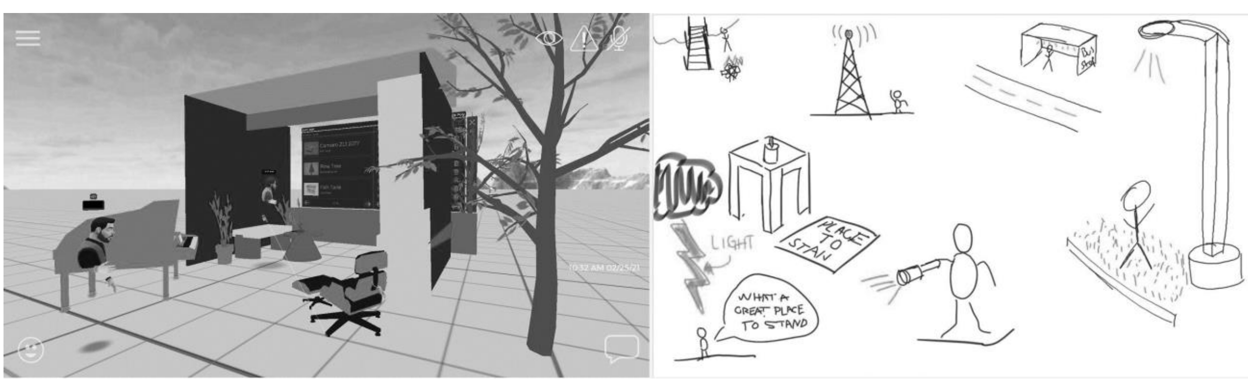

Figure 3. Examples of co-design prototyping in IVR using the collaborative virtual environment Rumii (on the left), and with NonVR using Google Jamboard (on the right). Students are prototyping around metaphors "CAVE - sit / shelter" and "MOUNTAIN TOP - stand / light"

5 DISCUSSIONS OF RESULTS

As noted in the related research, there were few empirical studies around how consumer IVR technology adds values or lends an important perspective to design education. This study builds on this related research. The results of this study showed a large difference in quantity favouring the NonVR co-design prototyping approach but a similar potential when considering the quality of either IVR or NonVR co-design prototyping methods. Additionally, there were clear statements from the student reflections showing an enthusiasm and recognition for the potential of IVR co-design prototyping. A further discussion of the results and additional anecdotal reflections offer insights regarding the prototypes and the potentials in the processes that developed them.

It was noted that Rumii, the IVR software, limited smooth co-design interactions in this rapid prototyping mode of work. This may have also impacted quantities of IVR versus NonVR prototypes and the rest of the scoring for the quality of the prototyping around the use of scale, shape, colour and form, the technical quality of the prototype, and even the novelty where students struggled more in a less familiar medium (IVR) to complete the tasks. Students found, for example, that Rumii had two modelling approaches that seemed to limit one teammate to create using a 3D line tool and the other teammate to work with a different tool for pre-set 3D primitive shape creation or prefabricated 3D models. This likely required more team negotiation and slowed the process and translation of ideas between co-designers.

Student reflections also incorporate additional important perspectives of the technical and co-design experiences of the study. Student comments captured the important idea that an embodied perspective brings to a co-design challenge around a prototype (or similar) with spatial potentials. Other distant digital technologies do not permit this important concept that exists in the physical studio environment.

The student comments around shortcomings together with the quality of prototypes completed, showed that some teams excelled in Rumii when they matched one teammate with the 3D sketching tool complementing the other teammate working with 3D modelling tools. These frame important concepts that any IVR digital design software used for early concept ideation and prototyping requires a well-designed user interface for rapid ideation and even differentiated for each student or designer. This again would match in concept to a physical studio environment where each student can sketch, model and create according to their individual creative potentials and developed skills and where they can easily communicate those ideas with articulation, persistence and substance.

6 CONCLUSIONS AND FUTURE WORK

By this initial small study, it is not possible to conclude what the differences and similarities are between co-designing prototypes in IVR compared to desktop solutions. We tentatively suggest that there might not be a difference, or that IVR design tools may lead to higher quality prototypes when students are co-designing. The study shows a clear advantage to NonVR prototyping in quantity where students are generally more comfortable in 2D digital design than they are with IVR technology. Nevertheless, IVR prototypes were of a very similar quality to NonVR prototypes regardless of the students' prior experience. However, considering the students' lack of IVR technology experience, when the students have more exposure to IVR technology it may affect the results, since a larger difference is expected between the results to favour the media students are more experienced using. Design education has incorporated many design techniques, like drawing and modelling over the years as a proven part of the pedagogical foundations. It bears serious consideration to employ IVR in the early phases of design education so students can adequately communicate their intentions as with as other design tools they are familiar with. Future studies conducted longitudinally across time are relevant to capture more experienced results with these IVR tools. These studies need to look at student development and learning and different software for prototyping to better understand outcomes and potentials of NonVR compared to IVR design tools. Besides, it is relevant for future research to conduct similar studies in other design classes in order to make conclusions on co-designing prototypes in IVR compared to other desk top solutions. Studies also need to be conducted with well experienced professional designers which may give different results to impact future design education practices.

REFERENCES

[1] Schwab K. (2017). *The fourth industrial revolution*. Currency.

[2] Richardson W. (2012). *Why school: How education must change when learning and information are everywhere*. TED Conferences.

[3] Sintema E. J. (2020). Effect of COVID-19 on the Performance of Grade 12 Students: Implications

for STEM Education. *Eurasia Journal of Mathematics, Science and Technology Education, 16*(7). doi:10.29333/ejmste/7893

[4] Mahdy M. A. (2020). The Impact of COVID-19 Pandemic on the Academic Performance of Veterinary Medical Students. *Frontiers in Veterinary Science*, *7*. doi:10.3389/fvets.2020.594261

[5] Sani I., Hamza Y., Chedid Y., Amalendran J., and Hamza N. (2020). Understanding the consequence of COVID-19 on undergraduate medical education: Medical students' perspective. *Annals of Medicine and Surgery, 58*, 117-119. doi:10.1016/j.amsu.2020.08.045

[6] Lee J. H., Yang E. K., and Sun Z. Y. (2019). Design Cognitive Actions Stimulating Creativity in the VR Design Environment. *Proceedings of the 2019 on Creativity and Cognition*. doi:10.1145/3325480.3326575

[7] Sanders E. B. and Stappers P. J. (2008). Co-creation and the new landscapes of design. *CoDesign, 4*(1), 5-18. doi:10.1080/15710880701875068

[8] Price S. et al. (2018). Reshaping Touch Communication. *Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems*. doi:10.1145/3170427.3170603

[9] Mitchell V. et al. (2020). *Digital Touch: Towards a Novel User-Experience Design Pedagogy* (EJ1249426). ERIC. http://files.eric.ed.gov/fulltext/EJ1249426.pdf

[10] Camba J. D., Soler J. L., and Contero M. (2017). Immersive Visualization Technologies to Facilitate Multidisciplinary Design Education. *Lecture Notes in Computer Science Learning and Collaboration Technologies. Novel Learning Ecosystems,* 3-11. doi:10.1007/978-3-319-58509-3_1

[11] Özgen D. S., Afacan Y., and Sürer E. (2019). Usability of virtual reality for basic design education: A comparative study with paper-based design. *International Journal of Technology and Design Education*. doi:10.1007/s10798-019-09554-0

[12] Gero J. S. and Milovanovic J. (2020). A framework for studying design thinking through measuring designers' minds, bodies and brains. *Design Science, 6*. doi:10.1017/dsj.2020.15

[13] Cindioğlu H. C. (2019). The Influence of Emergent Mixed-Reality Technologies on Design Thinking [Master Thesis, Middle East Technical University]. METU Institutional Repository.

[14] Lee J. H., Yang E. K., and Sun Z. Y. (2019). Design Cognitive Actions Stimulating Creativity in the VR Design Environment. *Proceedings of the 2019 on Creativity and Cognition*. doi:10.1145/3325480.3326575

[15] Jacobs H. H., Alcock M., and Kay K. (2017). *Bold moves for schools: How we create remarkable learning environments*. ASCD.

[16] Bosch R. (2018). *Designing for a better world starts at school*. Rosan Bosch Studio.

[17] Amabile T. M. (1982). Social psychology of creativity: A consensual assessment technique. *Journal of Personality and Social Psychology, 43*(5), 997-1013. doi:10.1037/0022-3514.43.5.997

[18] Carfagni M., Fiorineschi L., Furferi R., Governi L., and Rotini F. (2020). Usefulness of prototypes in conceptual design: Students' view. *International Journal on Interactive Design and Manufacturing (IJIDeM), 14*(4), 1305-1319. doi:10.1007/s12008-020-00697-2