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Immersive Collaborative VR Application Design:
A Case Study of Agile Virtual Design Over Distance

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ABSTRACT

Due to the recent COVID-19 pandemic, there has been a renewed interest in expanding the capabilities of remote collaboration tools. Studies show the importance of noticing peripheral cues, pointing to or manipulating real-world objects in face-to-face meetings. This case study investigated the opportunities of combining traditional video conferencing with a multi-user VR platform to enable the interactive collaborative design of a VR training experience between multiple stakeholders working from their homes. In this article, the authors reflect on the experience and contribute a fully online and immersive collaborative design workflow for future VR development projects. The authors believe this workflow is of benefit for remote collaboration in general, but particularly in severely restricted environments when face-to-face meetings are impossible.

KEYWORDS

Agile Software Development, Co-Design, Collaborative Systems, COVID-19 Pandemic, Remote Collaboration, Video-Conferencing, Virtual Reality, Working From Home

INTRODUCTION

COVID-19 is changing the way we work. Remote work and shifting company priorities have become the new normal for most employees. Many organizations have transformed entire business models and shifted working practices to teleconferencing, digital collaboration tools, and online products within a short time frame. Companies have embraced the use of online collaboration and training tools as a driver for change, with Virtual Reality (VR) and Augmented Reality (AR) technology providing new affordances to support the new work practices (Akpan et al., 2020; Liu et al., 2020; Teles et al., 2020). Remote digital collaboration through tools such as teleconferencing and shareable synchronous

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documents (e.g., Google Docs, MS Teams Apps) quickly establishes itself as a new norm of working together. There is excellent scope for VR and AR to improve further how collaboration occurs within remote digital working environments.

The five authors of this case study were team members on a project to develop an interactive safety training VR application for a construction company. The authors are researchers at multidisciplinary research labs in Australia with expertise in interaction design, education, and human-computer interaction. The authors utilize game design and technology to develop solutions that result in serious games applications and playable user experiences to address current problems. The team's industry-facing research uses an Agile workflow (see Related Work) to iteratively research and develop projects with active participation from industry partners. This process generally relied on regular face-to-face meetings to discuss the design and development at various milestones, including user tests with stakeholders such as the design team, industry partners, and end-users.

When COVID-19 struck and many businesses needed to transition to working-from-home, the authors had to rethink their practice to continue their work in the new normal. At the introduction of 'stay at home' restrictions in Victoria, Australia, in late March 2020, the authors proactively adapted a multi-user VR platform to enable collaboration during the lockdown. The research team developed the multi-user VR platform for a previous project. It enabled the stakeholders to meet in a VR environment using inexpensive VR devices (Oculus Quest) and to iteratively continue the collaborative design of the VR training experience without interruption while working from home.

In this case study, the authors reflect on their experience of co-designing and developing an Occupational Health and Safety VR training application entirely online with an industry partner in the construction sector without the use of face-to-face meetings. The authors' reflection of this case study contributes a fully online, immersive collaborative design workflow for future VR development projects. The workflow utilizes standard video conferencing and online collaboration tools combined with a multi-user VR platform, which provided the team with additional affordances that enabled the team to meet within the prototype itself. The additional affordances enabled playfulness, role-playing, improved mutual knowledge and agreement, while the iterative nature of the prototype itself contributed positively to the design collaboration process. The resulting workflow and the additional affordances provided by the multi-user VR platform enabled the team to effectively complete the project and eliminated the need for face-to-face meetings and associated travel time. The workflow, therefore, may be of value for designers and developers, whether face-to-face meetings are possible or not.

RELATED WORK

This work derived inspiration from prior works involving Agile Development, Remote Collaboration, and VR for Interaction Design.

Agile Development

Agile methodologies for developing software and electronic games have become very common in the industry. The Agile Manifesto (Beck et al., 2001) outlines the core values of various agile methodologies. Scrum (Schwaber & Beedle, 2001) is one of several agile methods characterized by short iterations called sprints. Each sprint delivers on a previously agreed list of requirements at each iteration. The Scrum method progresses projects iteratively through meetings with the design team, development team, and product owner stakeholders in short intervals.

Remote Collaboration

Collaboration can broadly be defined as having the following properties; facilitating information exchange and ideas, generating agreement, planning, and allocating tasks (Shelbourn et al., 2007). The key to effective collaboration is communication. The likelihood of a good result increases based on people's increased ability to more effectively understand one another and share information to facilitate the generation of ideas and agreement, and planning (Smith & McKeen, 2011).

Remote collaboration occurs when the parties are not co-located, which can be hindered by such issues as geographical distance, time differences, cultural and language differences (Noll et al., 2010). Communication technologies to support remote collaboration include asynchronous methods such as file transfer, email, other messaging systems, and synchronous methods such as real-time chat via telephone and video conferencing. A mixture of these methods is helpful for remote collaborations (Clark & Brennan, 1991; Heer et al., 2007). Among these communication channels, non-verbal communication is essential in the context of social VR technologies for remote collaboration (Maloney et al., 2020). Furthermore, presence is an essential concept for remotely mediated communication technologies, such as video conferencing, holograms, and augmented environments. Recent research has shown that 'honest signals,' i.e., non-verbal communications, are essential in communicating intentions, goals, and values in mediating social interactions (Themelis & Sime, 2020).

Furthermore, synchronous interaction is the key to establishing the theory of 'tele-proximity' to reduce the virtual distances of non-collocated participants. Video conferencing fulfills the requirement of synchronous interactions by streaming live video of collaborators but is often criticized for the lack of non-verbal communication regarding body movements and gestures due to limited camera view. Moreover, it can be challenging in video interactions to notice peripheral cues, control the floor, have side conversations, point to things, or manipulate real-world objects (Isaacs & Tang, 2002). Ironically, however, video conferencing can 'overload' collaborators with non-verbal facial cues through close-up camera view on the faces of others, leading to an increasingly common phenomenon coined as 'Zoom-fatigue' (Bailenson, 2021).

To fully enable rich interactions, mediated communication technology needs to balance verbal and non-verbal communications to ensure effective remote collaboration. This study considers the use of VR to build on remote collaboration tools to enable a shared space that enables natural collaborative behaviors.

VR for Interaction Design

Interaction design is an essential component of product and software development, centering on the interaction between users and products (Stolterman, 2008). The interaction design process consists of four iterative stages, including (i) user needs analysis to develop a better understanding of the user and how the interactive product can help to address the user needs, (ii) design of potential solutions to generate ideas often involving simple prototyping techniques and role-playing, (iii) prototyping at various stages of development, and (iv) evaluation, with stakeholders and end-users until the project is ready for deployment. Both the agile development and the interaction design process typically involve face-to-face meetings with project stakeholders at all stages.

The application of VR technology for interaction design, including prototyping, feedback, and evaluation, has been implemented for multiple domains, such as psychology (Bernardet et al., 2010), industrial design (Bennes et al., 2012), and media studies (Bolter et al., 2013). Previous studies have confirmed comparable effectiveness in uncovering and identifying usability issues between remote usability testing using video conferencing tools and traditional lab-based settings (Bastug et al., 2017; Chalil Madathil & Greenstein, 2011; Thompson et al., 2004; Tullis et al., 2002). The use of immersive technologies such as VR and AR in remote usability testing (Chalil Madathil & Greenstein, 2017) has also been shown to offer similar performance in terms of the number of usability defects detected by participants. In addition, VR offers benefits in enabling virtual prototype testing (Kuutti et al., 2001; Wolfartsberger, 2019), where participants can interact with virtual models of a prototype and provide usability feedback, with increased safety and test repeatability while reducing cost (Di Gironimo et al., 2013). VR also stimulates creativity for ideation purposes by generating highly interactive simulated environments (Lau & Lee, 2015). Graessler and Taplick (2019) propose a framework for using VR to support creativity by providing multimodal sensory stimuli and creating a playful and experimental atmosphere for the users in an open virtual space.

CASE STUDY

Construction Sector Occupational Health and Safety VR Experience

This case study was conducted in collaboration with an Australian commercial construction company. The project sought to improve the workers' and contractors' safety and health induction processes at their construction sites. Construction companies in Australia are required by law to conduct regular general site induction meetings with their construction workers and contractors and provide safe work methods statements (SWMS) with detailed explanations of all steps required for a job and the potential hazards and preventative measures. However, many construction workers and contractors fail to engage with the general training and the provided SWMS (Bluff, 2018). This project investigated the use of VR technology to deliver a safer working environment by providing construction workers with a more engaging method of hazard awareness training on a virtual construction site than reading through excessive amounts of safety documentation. The project started in July 2020 during 'stay at home' restrictions. The design team implemented the proposed immersive collaborative design workflow, involving a combination of video conferencing, shared online documents, and meetings within the VR prototype space. The VR system consists of a virtual construction site where discussion meetings occurred, as shown in Figure 1.

Technology

The VR prototypes were developed using the Unity game engine. For the VR hardware, the project used the commercially available Oculus Quest VR headset. As a stand-alone device, the Oculus Quest did not require a wired connection to a PC or a smartphone, and it supported precision room-scale and controller tracking without external sensors. Setting up the Oculus Quest was quick and easy, and the provided short tutorial allowed industry stakeholders to learn how to interact with the controllers in a short timeframe. The interaction with the virtual environment was intuitive, felt natural, and all members involved in the project could operate the hardware with very little training.

Participants

The project team consisted of eight people and an external systems manager from the construction company. The internal five academics and authors of this case study combined expertise in interaction

Figure 1. VR Occupational Health and Safety Environment

design, human-computer interaction, education, and game design. Finally, two professional staff members further supported the project with expertise in 3D content creation and animation, and VR development. The external systems manager had a limited direct experience of the affordances of VR. All academics had previously worked with the lead researcher. However, the systems manager had not worked with the project team before this project.

THE COLLABORATIVE VIRTUAL DESIGN WORKFLOW

Design Workshops

The authors designed and developed the prototype construction site with three hazard scenarios over seven design workshops. The workshops followed the Stanford Design Thinking methodology (Tschimmel, 2012). This methodology is characterized by an iterative process that seeks to generate an improved understanding of the target user, challenges assumptions, redefines problems, and develops solutions through a fast-paced set of short exercises. The project team used Zoom, Google Slides, and progressively iterated VR prototypes. The software to support these collaborative design workshops was chosen based on the team member's familiarity.

The first workshop focused on generating initial ideas for VR-based Occupational Health and Safety user experiences. In the team's first meeting, the team only used Zoom and Google slides for real-time communications. Zoom (2020) is a video-based conferencing tool that allowed the team to meet online through video and audio streaming. Zoom users can generally choose to record sessions, collaborate on projects, share or annotate on one another's screens, and work in small groups with one easy-to-use platform. The team generally used Zoom to collaborate on the design. Some of the design thinking process's ideation tasks required working in small groups, which was enabled by Zoom breakout rooms. While all members of the design team had worked with the lead researcher in the past, many team members met for the first time in this workshop.

Not all design team members were designers and, therefore, unfamiliar with online design collaboration tools such as Miro (RealtimeBoard Inc., 2020) or Mural (Tactivos Inc., 2020). However, all members of the design team had used Microsoft PowerPoint in the past. Google Slides, which is very similar to PowerPoint in many ways, was helpful as it allowed the team to edit a document collaboratively in real-time. It also provided the team with simple to use graphical tools to facilitate drawing tasks. Google slides were used to arrange the design thinking tasks in small activities that prompted action from all participants or smaller groups to collaborate on a task on the same slide or different slides simultaneously during the design thinking process.

Cramton (2001) outlines the importance of face-to-face communications with all its non-verbal gestures, silences, and other nuances for establishing essential 'back-channel' feedback required for free-flowing information and idea exchange. However, virtual remote meetings enabled through video conferencing technologies such as Zoom, and collaborative editing tools such as Google Slides, cannot effectively capture all these qualities of face-to-face communication (Vrzakova et al., 2021). Moreover, there are no readily available tools to address the challenge of collaborating on designing a three-dimensional environment of a real-world construction site and associated Occupational Health and Safety scenarios. Construction workers are accustomed to scenarios that enable spatial interactions, such as pointing and physically moving objects. Therefore, instead of improving on tools such as Zoom, the authors instead supplemented the remote collaboration experience with the VR technology itself.

The first workshop followed the Emphasize, Plan, Brainstorm steps of the Design Thinking process. Using Zoom, the team developed a better understanding of the target audience by interviewing the construction company member, the systems manager about the target audience, and the practices related to the safe work education training that the VR training application aimed to address. Using Google slides, the team then collaboratively determined the intended impact of the VR prototype.

The team then split up into groups of two to generate initial ideas for subsequent refinement over the coming sessions.

Virtual Reality Prototype

The outcomes generated by the first session led to the development of a basic VR prototype. From the outset, the multi-user VR platform provided the stakeholders (up to twenty) with the ability to meet in real-time VR space with identifiable avatars (editable name tag above avatar), voice support, teleport controls for moving around the space, and laser pointers to indicate areas of interest. The multi-user functionality had already been developed and refined in a previous unrelated project by the research team. The initial prototype's environment consisted of texture-free 3D models of a building site. The prototype provided the basis for the Design, Evaluate, and Feedback of the process. The prototype was kept barebones and relatively simple through the initial iterations to allow for rapid prototyping. Ideas could be tried and tested, evolved, or discarded without too much commitment or cost. Only gradually, as ideas cemented and became considered as final for the end application, did the prototype gain in complexity and production costs.

This prototype was demonstrated to the entire team just one week after the initial meeting, and its' subsequent iterations provided the basis for discussion, role-play, and user testing. The design team members were provided with step-by-step instructions to install an Android application package file onto their Oculus Quests. The initial prototype featured a construction site and a few plant objects such as a crane and bulldozers. Once the VR application was started, the team would spawn as virtual avatars at a meeting point inside the prototype. The virtual avatars only contained a virtual head and hands, without a torso. The virtual hands were controlled with six degree-of-freedoms by the left and right hand-held controllers of the Oculus Quest. Buttons on the controllers enabled a few simple hand gestures such as a 'thumbs-up' and a pointing finger. In addition, each design team member could identify themselves by inputting their name, which was displayed as a name tag on the avatar's helmet.

Subsequent workshops involved virtual 'site walks' led by the systems manager of the construction company. The participants utilized a teleportation mechanism with a virtual laser pointer to jump across large distances on the site. Short distances could be traversed by users walking provided that sufficient physical space was available. A site walk triggered discussions where team members shared ideas and knowledge based on the surrounding objects. Common tools (angle grinders and circular saws), building materials, and OH&S controls (traffic cones) could be picked up by the participants and freely positioned to set the scene. Stakeholders could also use their laser pointer to indicate points and locations under discussion leading to the iterative development of the virtual construction site illustrated in Figure 2. Role-playing was a useful mechanism to refine the development of the safety training scenarios through subsequent design meetings and workshops. The design team members took on different construction roles and acted out these various accidents leading to the development of the scenarios illustrated in Figures 3-5: using an angle grinder, excavating a trench, and using a scissor lift.

Each new version of the prototype was explored and tested by the design team, with all team members role-playing the accident scenarios. Discussions started within the VR prototype and then

Figure 2. Construction Environment Progression

Figure 3. Angle grinding accident

Figure 4. Trench excavation accident

Figure 5. Scissor lift accident

continued in the following Zoom meetings. The authors recorded each VR session by capturing the video feeds from several researchers' viewpoints to capture the key insights discovered during the VR prototype testing sessions. The authors subsequently reviewed this footage during the following Zoom session. In the Zoom session, the authors used Google slides as a whiteboard to make notes to assist the decision-making process and further refine the ideated scenarios. Effectively, the prototype was designed remotely without face-to-face meetings.

METHOD

After completing the Construction VR Safety Training application, the academic researchers within the design team felt that the remote collaboration had been particularly successful and that the involvement of the VR had offered functional affordances within the collaborative design process. To examine this further, the research team conducted a semi-structured interview about the Immersive Collaborative Design process to define and better understand the affordances of the workflow.

The audio recordings were transcribed using automated transcription software Otter (Liang, 2019) and checked by an independent research assistant. The transcriptions were loaded into NVivo and analyzed using Inductive Thematic Analysis (Braun & Clarke, 2006). Initial coding was conducted by two researchers working independently. The authors began with an inductive approach, then grouped themes under central topics, informed by the interview guide. Once all data was coded and a set of initial themes was considered, a data session with additional researchers took place. In this session, the researchers closely reviewed the coding and preliminary themes from the data. The initial data coders further refined these themes. The transcribed quotes presented in the findings below are representative of the themes they discuss. All researchers had experience in conducting qualitative data analyses. The following section presents the findings from the analysis.

RESULTS

The results of the thematic analysis are grouped into five themes.

Communication

The participants felt that communication was supported by providing a shared spatial visualization that enabled the team to obtain feedback and exchange knowledge in spoken form through body language, non-verbal gestures (looking with the head in the direction of an object and pointing with hands, using the laser pointer), and interactions through the multi-user VR platform.

The VR platform provided the team with a shared spatial visualization. The platform provided a sense of presence: "*you could be in that environment, interact with things and, look over your shoulder…" (P3); "VR gives you the ability to see what everyone else sees, and everyone in that environment is able to collaborate directly inside that environment.*" *(P1).* Information could be exchanged through demonstration by *"show[ing] people what you mean.' (P3).*

Despite the lack of a full body avatar, and only having hands and a head, participants felt body language was sufficiently demonstrated through hand gestures and head movements: *"…the gestures tend to make it a little bit more natural, you know, just the ability to see someone's hands moving, while they talk. etc." (P2); "… avatars … eye blinking and mouth moving… [made it] feel like you're actually in that environment, on a construction site, talking to someone." (P3); … you're talking around the table. And it's funny, because you actually make eye contact with people when you're speaking to them." (P3); "the body language helped significantly to improve the communication." (P5); "…we don't have a virtual body, so the gestures carry across [what] the facial expression doesn't carry across" (P4).*

The VR platform enabled the team to obtain feedback and exchange knowledge about specific objects in the virtual environment. This included being able to criticize the visualization of construction equipment: *"actually talk directly to that environment with other people..." (P1);* "*[the industry partner] could point to an area and say... it needs a concrete truck, and it needs a concrete pump, to make that look realistic*" (P5); "*altogether, talk about various objects in the space*" *(P5); "[the industry partner] could, obviously provide us with his expertise, of being on a lot of construction sites." (P5).*

Playful Ideation

When team members reflected on the process of forming new ideas and concepts for the design of the prototype, the participants reacted positively to the playful experiences provided by the shared VR space.

The VR space motivated the design team to engage playfully. The design team reflected on the playful aspects of the VR experience. *"There are a lot more playful activities in VR, like when falling was an option that was made available. A lot of people tried that." (P4);* All design team members engaged in role-playing: *"you do the work, and you go into the trench … and others were watching" (P6).* The playfulness was enabled by the virtuality of the technology, in which the team could experience the accident scenarios on the virtual construction site without physical consequences. This theme provided positive affirmation for the project's direction of implementing accident scenarios for the final prototype. Moreover, the physical distance provided each team member with more confidence to playfully engage with the environment: "*There wasn't any awkwardness in VR, because we were not located physically in the same space." (P4).*

Ideation and Rapid Prototyping

The participants described several key attributes that they valued in relation to the generation of new ideas.

The spatial context provided by the VR space assisted the team with the idea generation process. The visualization of the circumstances that formed the setting of a construction site provided the fertile ground on which new ideas could be developed: "*VR is the best because it provides some context... most of the ideas came to me when we were in the VR session" (P4); "when people put forth an idea that you deem may not be as effective, it's actually a great thing, because you can demonstrate it relatively quickly and easily" (P1).*

The team was generally impressed by the speed with which the prototype developed: " *... it's faster because the client, compared to other meetings where we have to describe it verbally or in text or in photos and pictures, but rather enable to take the client directly into VR" (P4); VR is readily adaptable, you can change it at any time.*' (P1).

The rapid prototyping process was flexible and kept everyone well informed of the progress: '*... good thing about the VR was that you're testing it, and you're immediately finding out about glitches or issues that need to be addressed prior to the next meeting" (P2); Every week, we would jump in and someone go like, "Oh, can we move that truck there? And like, have that backing out, then?" '(P3); I think the platform of meeting in VR was, was so important to follow up with our ideation, and, you know, and our, our ideas and see what worked and what didn't.' (P2); "the industry partner always knew what we are going to do, and then also had the experience just a week later, of the new prototype.' (P5); 'I was pleasantly surprised at how fast a prototype was built and all the features that were made.' (P4).*

Face-to-Face Communication

Amongst the team, there was a shared sentiment about the qualities of face-to-face that were missed: "*good to kind of actually see the client in person" (P6); "see them and see their body language." (P2); 'lack of certain personal things that we do as human beings, when we meet face to face, [like] we shake each other's hands which is a sign of trust-building" (P5); "all different types of nonverbal communications [would have helped] to generate ideas a little bit better" (P4).*

Overwhelmingly the team members felt that the convenience of meeting online generally made up for its shortcomings of decreased levels of both verbal and non-verbal communication.

"*you didn't have to factor in travel time" (P7)*; "*the convenience, … to almost jump in at any time, really" (P1); "it would have been so much harder [to schedule 7 people]… to meet at one location..." (P2).*

The team was able to meet more regularly, and meeting regularly was regarded as a significant advantage: *"We were able to have more meetings in a short period of time." (P5); "I don't think we would have met as regularly as we did..." (P4).*

Limited Non-Verbal Communication

Upon reflecting on the shortcomings of meeting remotely, team members commented that an improved VR avatar could potentially increase the presence felt by participants as well as the non-verbal communication: "*it would help naturalize person to person interactions in VR… be able to track where they're looking"* (*P6); "the experience would be so much more effective if you saw the body." (P2); "..as soon as we could see the mouth moving, and the eyes blinking… also, embedding natural hand gestures for putting your thumbs up, or pointing at something with your index finger … helped significantly to improve the communication" (P1); "more needs to be done there to record facial expressions, eye movements [and] gestures." (P1*). Initially, in the first five prototypes, the avatar head model only rotated based on the users' head movements. However, after the fifth week, the addition of mouth movements synchronized to speech and artificial eye movements and eye-lid blinking was viewed by all participants as a huge improvement. In addition, avatar models were updated to include personal protective equipment such as hard hats, safety glasses, and earmuffs that are typical on construction sites.

DISCUSSION

This case study implemented and reflected on a workflow that enabled the design team to design a VR training application prototype without face-to-face meetings during COVID-19 lockdown. The team developed an Occupational Health and Safety training prototype in seven design sprints in just eight weeks. Despite the clear drawbacks of limited nonverbal communication in regards to the reproduction of body language, facial expressions, and overall embodied visualization of each design team member through their avatar in VR, the findings indicate that, overall, the mixture of using video conferencing, online collaboration tools and multi-user VR environments, was successful in enabling the development of the prototype. Notably, the multi-user VR component provided a playful, relatable, and powerful immersive experience for the design team. Prior research into prototypes and collaboration indicates that prototypes support team communications by providing context and clarity, overcoming barriers that arise from stakeholders having different domain expertise (Kleinsmann & Ten Bhömer, 2020; Lauff et al., 2020). The results of this study align with this prior research.

Developing the prototype using an Immersive Collaborative Design workflow demonstrated that it is not only possible to design VR applications in this way but, in some respects, superior to the traditional approach of meeting face-to-face. The COVID-19 lockdown was a circumstantial factor for the project; however, the implication for the findings can be applied to many other scenarios, whether remote collaboration is required or not. The design team indicated they intend to continue using this workflow for further projects and to develop further guidelines for this approach so that others in these fields may benefit from it. Collaborating and designing online and with VR drastically reduces the time demands of meeting face-to-face. Not requiring travel time increased the productivity of all team members and made it easier for all participants to schedule weekly meetings. Zoom and online tools can provide the design team with the ability to work collaboratively on the early phases of the design thinking process. At the same time, the multi-user VR platform can provide the design team with context and significantly enhance the quality of communication while also introducing role-play as a means to generate new ideas. Team members found they could quickly share their ideas or understand other team members with little confusion or misunderstanding.

Being physically located in private spaces surprisingly increased the participants' engagement in playful activities and reduced awkwardness when engaging in playful activities or performing in front of other team members. This may result from the physical isolation or the limited avatar design and therefore warrants further investigation.

LIMITATIONS

From a study perspective, the authors of this article were also members of the design team. This introduces a possible bias in how the information was analyzed. However, the thematic analysis used upon the data should minimize this bias. Another limitation is that the research is based on a single case study. As mentioned in the discussion, the findings here align with prior research on prototypes and collaboration. The design team appreciated the approach taken for this VR prototype, and they intend to use it again for future projects with industry partners. This will offer additional case studies to supplement the data and further develop this research.

Furthermore, this article focuses on the reflective experiences of the designers and stakeholders rather than the perspective of end-users. The focus of the experiment has been on the interactions around the collaborations; therefore, in this article, we did not collect quantitative data regarding presence, comfort, and cybersickness. Through the interviews, no participants reported any discomfort or experience of cybersickness. We have subsequently conducted an end-user evaluation which are reported in [citation under review].

From a technical perspective, the prototype's current implementation only offered voice communication and a limited virtual representation limited to participant head movements and hand gestures without a full-body representation or facial expressions. Similarly, hand gestures were limited to thumbs up and pointing. Future research is already addressing this by providing avatars with an increased amount of control, including hand tracking (Wu et al., 2019), full-body avatar tracking (Caserman et al., 2019), and facial gesture tracking (Hickson et al., 2019) and is expected to become available to mobile headsets in the near future.

CONCLUSION

This case study explored a timely topic of facilitating a collaborative design experience around developing a VR training experience. Given the current extent of the worldwide COVID-19 pandemic and current restrictions that mandate that people work from home in many countries, the team implemented and tested a fully online collaborative design approach based on online video conferencing, collaborative web tools, and VR to support a collaborative design approach to develop a prototype VR experience for construction workers. The evaluation of the design team's experience found that the process was overall effective and, in some cases, superior to the usual face-to-face meeting approach. By eliminating the need for all stakeholders to travel to meetings, the participants could meet more frequently as attending a design meeting did not demand as significant an investment of time. Beyond the remote collaboration aspects, the design team members were impressed by the additional affordances provided by the VR experience. The VR provided immersive and spatial opportunities to use role-play to generate and evaluate ideas. Keeping the initial versions of the prototype relatively simple allowed for rapid prototyping where ideas could be quickly tried and discarded without too much cost. The VR also facilitated the collaboration process by reducing ambiguity, communicating progress, improving mutual knowledge and group agreement. This work contributes to a growing body of experiences demonstrating how interactive, playful, and game-inspired tools and approaches show alternative ways to facilitate teamwork and collaboration.

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