Improving the efficiency of virtual-reality-based ergonomics assessments with digital human models in multi-agent collaborative virtual environments

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Abstract

Often new digital tools are introduced alongside existing tools and workflows to augment and fill gaps in current processes. Virtual and augmented reality (XR) tools are currently being deployed in this way within design processes, allowing for interactive visualization in virtual environments including the use of DHM tools. Currently, the focus is on how to implement XR as a stand-alone tool for single user scenarios. However, in collaborative design contexts, screen-based and XR tools can be used together to leverage the benefits of each technology maximizing the potential of multi-user design processes. XR allows for an immersive exploration of designed objects in 3D space, while screen-based tools allow for easier notetaking and integration of additional non-3D software and meeting tools. Ensuring that these technologies are integrated in a mutually beneficial manner requires a framework for determining the best combination of technologies and interfaces for diverse design teams. This paper presents a framework for performing collaborative design reviews in a digital environment that can be accessed using both XR and 2D screen devices simultaneously. It enables asymmetric collaboration to provide each design team member with the technology that best fits their workflow and requirements.

Keywords: Collaborative design, Asymmetric collaboration, Extended Reality

Introduction

Developing a product is a complicated process that often requires collaboration from various stakeholders to succeed (Redante et al., 2019). Often, stakeholders in large organizations collaborate with globally dispersed teams in the product design process. Moreover, recent events, such as the Covid-19 pandemic and awareness of climate change, have further boosted interest in reducing the air travel for in-person meetings (Becken & Hughey, 2022). As a result, there is increasing demand for tools that can effectively mediate remote collaboration in all stages of the design process.

Design reviews are one stage of the design process that can often require collaboration among multiple stakeholders and have traditionally depended on in-person meetings and videoconferencing tools. In design reviews, several stakeholders come together to consider and critique a current design before production plans are finalized. The design review process is an essential control point for any design project to transit from one stage to another and can include not only assessing the physical properties of designed artefact but also ergonomics and human factors through the use of DHM tools (Huang, 2002). Often, the designers and production managers performing these reviews are not geographically co-located, and remote collaboration tools can improve workflows when travel is not possible or not prefered (Tea et al., 2021). For many companies, videoconferencing apps and their corresponding screen-sharing capabilities constitute state-of-the-art for this kind of remote collaboration. Extended reality (XR) tools have recently been incorporated into collaboration workflow (Cooper et al., 2021). However, they are typically integrated alongside existing videoconferencing workflows and treated as another screen to be shared with online collaborators (Chen, 2021). While this approach is functional, it limits and misses many key benefits that XR can introduce into a design process. While a more integrated XR solution is needed to access these benefits, it is also important to consider that not everyone will benefit from using XR technologies in a collaborative design process (Burova, Mäkelä, et al., 2022). As a result, we anticipate that future collaborative design processes will involve a mixture of technologies resulting in various asymmetries between collaborators. Because this kind of intentional mixing of technical systems is new in the context of collaborative design, more frameworks are needed for organizing technologies, users, and user roles (Reski et al., 2022). In turn, such a framework can support determining user needs and assessing implementations for multiuser asymmetric (i.e., collaboration using different devices).

This paper presents an initial framework for asymmetric XR collaboration and applies it to a simple collaborative design review in a digital environment using both XR and 2d screen devices simultaneously. The central idea of this framework is to enable asymmetric collaboration to provide each design team member with the technology that best fits their workflow and requirements. We ran a small pilot study to validate the framework using an existing workflow at the Chinese-Swedish company CEVT.

Method

While some tools for multiuser XR and asymmetric design exist (Burova, Palma, et al., 2022), there is little guidance regarding how these tools might be best used for design teams. Discussions with CEVT gave us insights into their current workflow and needs, and we developed a prototype software accordingly. After that, we evaluated the software in a controlled environment to check the viability of the proposed framework. This process is illustrated in Figure 1.

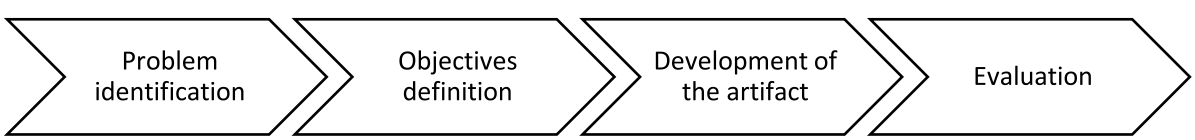

Figure 1. Development process

Problem specification and initial prototype

Some companies, including CEVT, have started including XR in their design review processes to support assessment of ergonomics and assembly feasibility within DHM tools. The expectation is that the use of digital tools and XR technology will allow for more efficient multi-user remote collaboration. However, current XR applications in DHM have limited multiuser interfaces, minimal screen sharing options, limited interaction options and underdeveloped workflows from CAD to XR tools.

CEVT currently implements XR-based design reviews by having one person in XR share their screen over a videoconferencing app with different stakeholders (see Figure 2). These stakeholders (the audience) watch as the person in XR (the VR navigator) assembles the product component by component. After each component is assembled, the VR navigator places a DHM manikin in an expected position and pose for that assembly step. Once the appropriate stakeholders have evaluated an assembly step and identified issues and risks for the current component, they move on to the new component.

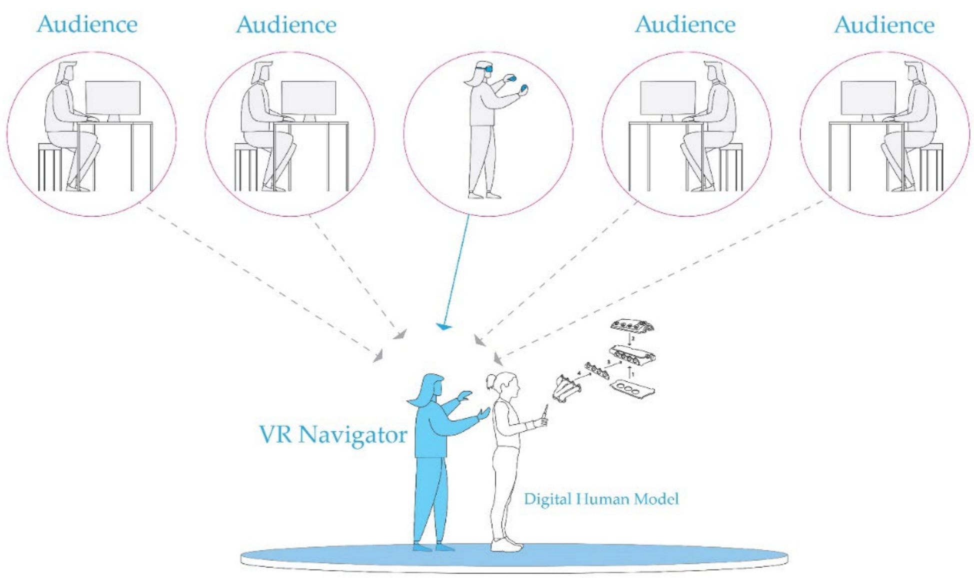

Figure 2. Illustration of current design review approach.

Having only one person able to navigate the environment (the VR navigator) and limiting the audience's view to the VR navigator's perspective are significant limitations in this workflow. The audience includes operators, manufacturing engineers, mechanical engineers, and ergonomists, among others. Not everyone needs the same kind of information or interaction capabilities, and their needs may not match the aims and focus of the VR navigator. As an initial division of roles, we identified that some users needed more direct engagement with the 3D environment and that others needed to split their attention among other software tools that are not and may not be integrated into the 3D environment. As such, for some users XR tools are likely be beneficial but for others, the tools may be a hindrance, requiring frequent changes between the XR device and a 2D screen. In both cases, the ability to freely navigate the 3D scene appeared potentially valuable meaning that it may not be beneficial to limit free movement to only the XR users. Thus, it may be helpful if XR users can navigate the digital environment by using controllers or their bodies and screen-based users can use a keyboard and mouse to navigate the digital environment. Taking these insights, we developed a prototype multiuser asymmetric design review environment, as illustrated in Figure 3.

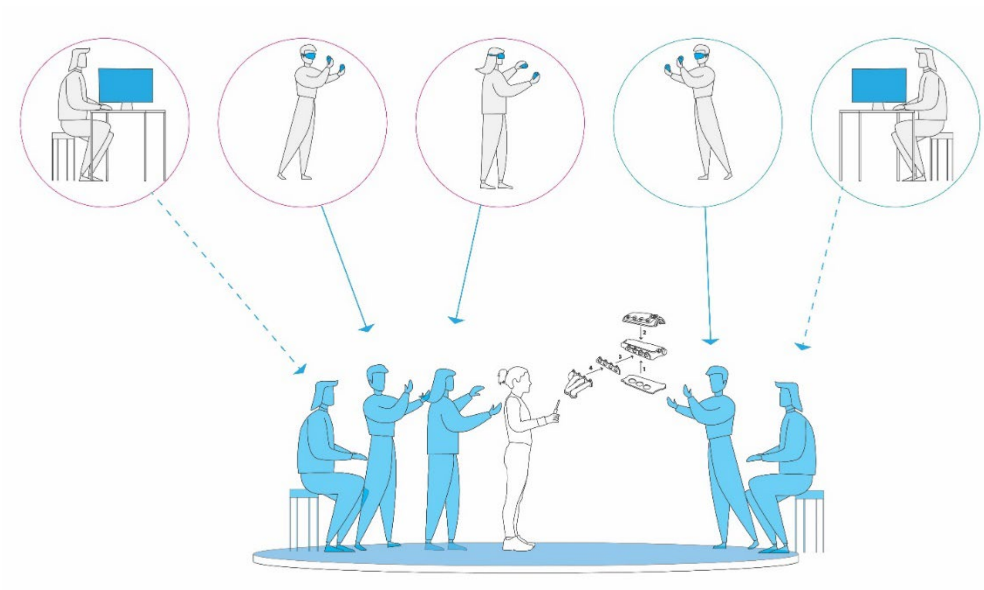

Figure 3. Illustration of software prototype roles and interfaces

As an initial solution, we developed a shared digital environment that the users can connect to either using a PC with a traditional monitor or an XR device (Figure 4). All users can navigate the environment, have avatar representations, and communicate using voice. The avatars allowed users to see one anothers location in the environment but were not intended to be a detailed representation of the users body state. Only users who access the digital environment using XR equipment can grab and move objects. Object models based on 3D CAD designs could be imported into the environment and simple interactions (grab and move) could be specified for the objects as needed. A digital human manikin is included in the environment which can be manipulated by moving the black spheres (visible in figure 4) attached to its hands and head allowing for visualization of static poses in an assembly process. In the current implementation, all the objects and manikin movements are visible to all the users connected to the digital environment, though visibility could be limited based on user role or even clearence status within the company.

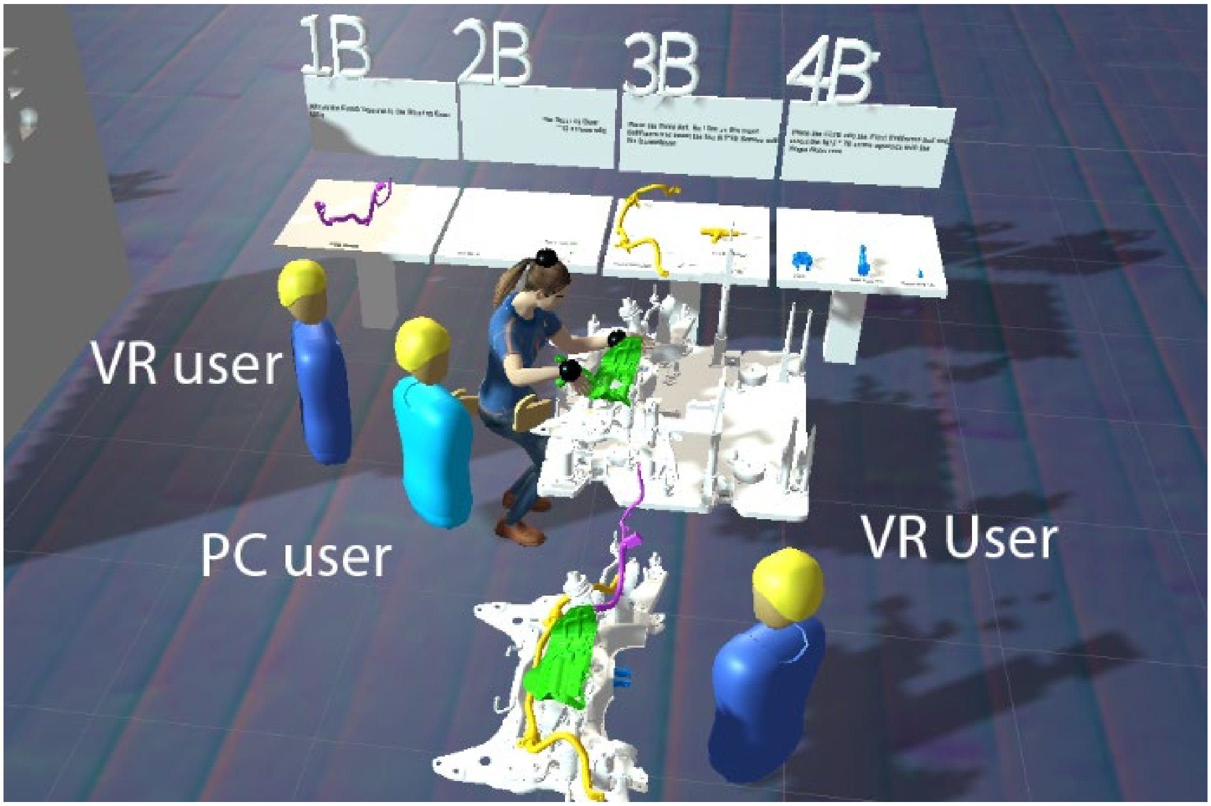

Figure 4. Digital environment with 2 XR users and one PC user

Material used in the development

We developed the prototype using Unity 2020.3 (Unity technologies, San Francisco, California). The software was built to run on either a Windows PC with a monitor or on the Oculus Quest 2, though the program could run on other XR platforms if needed. Users movements, object interactions and verbal conversations, were synchronized using Photon, a cloud service for multiplayer games (Exit Games, Hamburg, Germany). The manikin mesh was built in makehuman (*Make Human Community*, 2022), and its motions were driven by the FABRIK solver (Aristidou & Lasenby, 2011) in the Unity plugin FINALIK (*RootMotion*, 2022)

Evaluation

A pilot study was developed to test the design review tool and validate this framework implementation. The objective of this evaluation was to determine if collaboration in XR could be more effective when all users can navigate the digital environment. In addition, we evaluated the user experience to identify the impact of free navigation and asymmetric tools.

Fifteen healthy subjects split into three groups were used as test subjects for the pilot study. All participants are current or recently graduated students at the University of Skövde. Ten participants are in the age range of 18-25 years, three participants are between 26-30 and one participant each is in the age range of 31-35 and 36-40. They were asked to perform five assembly tasks with the current approach used by CEVT (see Figure 4 condition A) and with the proposed for the prototype (see Figure 4 condition B). In condition A, there was an VR navigator, an observer and an assessor. The VR navigator assembled the components following instructions presented in the scene and posed the manikin. The observer and the assessor helped identify issues in the assembly process but were only able to see the scene from the VR navigators point of view. In condition B, the VR navigator's tasks remained the same. However, the assessor was in XR, and the observer used a PC with a 2D screen. The assessor and observer were allowed to navigate the digital environment and select viewing positions independently, but they could not interact with the assembly components or manikin.

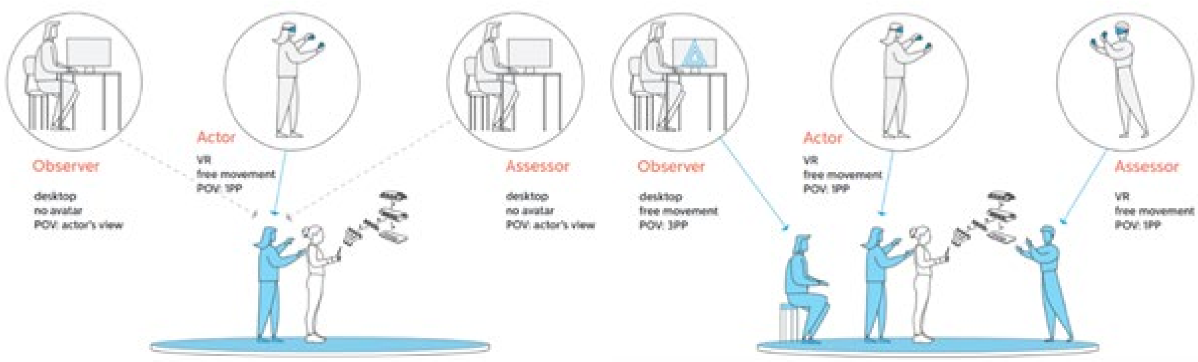

Figure 5. Illustration of condition A (right) and condition B (left)

Condition order was counterbalanced such that three groups started with condition A and two groups started with condition B. There were three issues planted in the sample assembly task: the posture of the manikin, an unfeasible sequence of assembly operations, and one required tool for the assembly not fit in the spot where it had to be used. Participants were instructed to note any issues they saw in the assembly process. We hypothesized that the participants would be more likely to find these issues when all of them could independently navigate the digital environment (Condition B). After the study, the participants completed a questionnaire (see Table 1) evaluating their experience comparing the two conditions (Schrepp et al., 2017). The first four items evaluate pragmatic features of the system and the second four categories evaluate hedonic features.

Results

In condition A, the participants correctly identified issues 12 times and missed or mis-identified issues 11 times. In condition B, the participants correctly identified the issues 19 times and missed or misidentified issues 11 times. Figure 5 shows the data for the identified issues by the participants divided by correctly identified, missed, and misidentified. Correct identifications involve identifying a planted issue while misidentification involves indicating an issue exists that was not planted. In the case of misidentification, it is possible that an issue did exist, but later assessment suggests this was not the case. When an issues was planted but not identified it was counted as being missed. Note that in situations where one issue was planted and the participant reported a different issue the response was counted as both a miss and a misidentification. Results from the questionare are summarized in Figure 7.

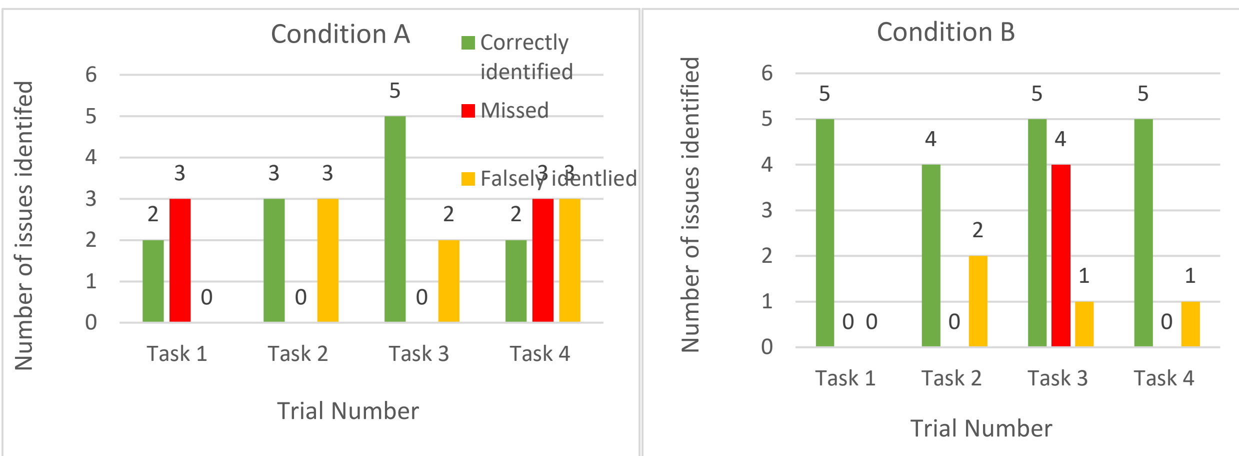

Figure 6. Identification of issues by the participants.

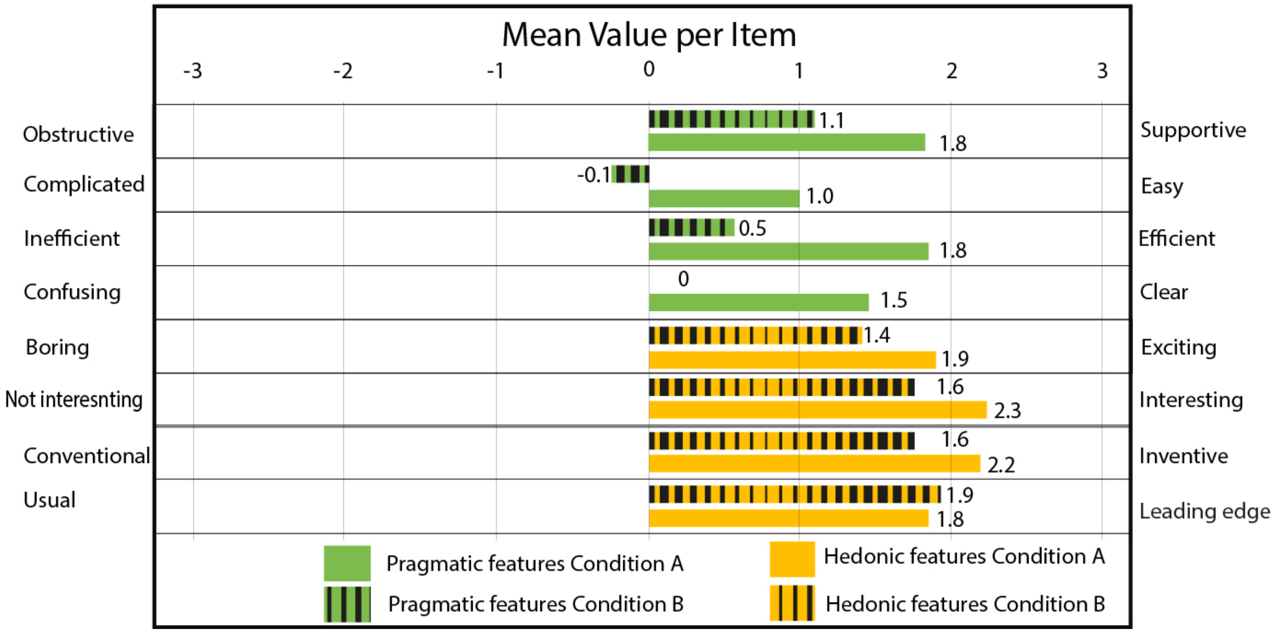

Figure 7. Mean values for the short user experience questionnaire conditions A and B

Discussion and Conclusions

In this pilot study, participants found the planted issues more easily when they could independently navigate the digital environment. In general the results show a consistent trend towards condition B in terms of correctly identifying planted issues. Note, in condition B task 3 the large number of missed issues is likely due to an error that resulted in there being 2 planted issues, so the spike may be due to the fact that users did not expect 2 errors in that case.

The user experience questionnaire also seems to indicate that the participants found condition B to be more practical and enjoyable. Given the size of the study and the limited scope of investigation, it is not clear if the enjoyment is related to the ability to navigate independently or the more streamlined inclusion of XR in condition B.

While the pilot and corresponding assessment is limited, the results are at least positive and indicative more work that needs to be done. Specifically, future work will need to investigate if there is any particular benefit due to XR integration or if the ability to navigate independently is sufficient for improving issue identification and creating an enjoyable process.

Collaboration and meetings using videoconferencing apps have become the norm. While design collaboration using screensharing and videoconferencing apps provides a functional solution that works now, more work is needed to enable effective collaboration within DHM and CAD tools. Specifically, consideration of how different roles in a design process might benefit or be harmed from hardware and software constraints. Future XR design tools should consider not just multi-user XR collaboration but also how asymmetric collaboration can be incorporated. In this paper we have demonstrated an initial conceptualization of how asymetric tools can be enabled for remote collaboration.

Future work will focus on integrating more forms of XR while also making a more thorough and clear investigation of the benefits and potential challenges of using aysmetric XR systems in design processes.

Acknowledgements

This work has been made possible with the support from the Knowledge Foundation supported research environment INFINIT at the University of Skövde, in the project Synergy Virtual Ergonomics (SVE), Recruitment and Strategic Knowledge Reinforcement initiative and with support from VINNOVA. This support is gratefully acknowledged.

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