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How Can XR Enhance Collaboration with CAD/CAE Tools in Remote Design Reviews?

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Abstract.

This study studies the challenges of effective communication and collaboration in remote design review meetings (DRMs) and explores the potential of Extended Reality (XR) technologies to address these challenges. The research focuses on identifying recurring communication issues and the preferences of companies within the context of remote DRMs. The study involves qualitative content analysis and industry workshops to uncover the current problems with conventional approaches and the aspirations of companies regarding improved collaboration in the DRM process. Drawing upon the insights gathered from both the workshop and design review observations, this paper highlights the features that are critical for collaborative software to handle online design reviews.

XR technologies offer immersive and interactive experiences that can transform communication and collaboration in the context of DRMs. By identifying the specific challenges faced in remote DRMs and understanding the desires of companies, this study sets the stage for a more efficient and effective collaborative process. It emphasizes the adaptability of XR technologies to meet industry needs and integrate seamlessly into existing workflows. The study concludes by highlighting the potential for XR technologies to enhance collaboration in DRMs, making them a valuable tool for various industries.

Keywords. Collaboration, Extended Reality, Design Review

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1. Introduction

Computer-Aided Engineering (CAE) and Computer-Aided Design (CAD) software are a collection of digital tools and applications that are essential in modern industry, and likely, they will continue to be [1]. Traditionally, these tools have not incorporated many collaborative functionalities. With the decentralization of production systems, outsourcing manufacturing operations to foreign countries, and changing workforce preferences and demands, there is a shift towards remote collaboration [2,3]. As a result, there is a growing demand for CAD/CAE tools to adapt to remote collaboration. While CAD/CAE is a broad term, this paper will focus on 3D CAD/CAE tools used in product realization. These tools normally consist of a virtual 3D environment where information about future products is represented. This information can be related to various aspects, including mechanical aspects and manufacturing aspects. While there are many tools with different purposes, they commonly have a virtual 3D environment where all this information can be accessed and edited. Despite videoconferencing platforms like Microsoft Teams and Zoom being available, CAD/CAE tools could enable their existing virtual environments for collaboration instead of relying on external applications that, in some instances, can create friction in the collaboration [4].

There is an apparent demand for CAD/CAE tools with built-in collaboration features, as evidenced by the emergence of new CAD/CAE tools that are designed specifically for collaboration, many of them being cloud-based [5]. However, there are some challenges to transitioning to these new CAD/CAE tools. Many companies store large amounts of data in existing platforms, making switching to new platforms difficult. Additionally, many of the latest CAD/CAE tools are web-based, which can raise concerns about data security and privacy [6]. As a result, the industrial sector would benefit significantly if existing CAD/CAE tools could be adapted to the changing landscape of remote collaboration practices.

Integrating extended reality (XR) technologies into CAD/CAE software is another significant trend in the industry. XR is an umbrella term encompassing various immersive technologies that blend digital and real information to provide users with immersive experiences. These technologies include virtual reality (VR), augmented reality (AR) and mixed reality (MR). XR enhances the capabilities of these tools by providing immersive and interactive environments for design, modelling, and engineering tasks. XR technology not only improves the design and visualization process but also supports collaborative efforts by allowing geographically dispersed teams to work together in shared virtual spaces, further addressing the demand for remote collaboration in CAD/CAE [7,8,4]. While XR can be quite useful and can add a lot of value to CAD/CAE software, it is worth establishing where that value can be added within CAD/CAE software and what functionalities of features XR can bring to CAD/CAE tool.

A situation where XR in CAD/CAE tools and collaborative features normally come together in design review meetings (DRMs). DRMs are essential gatherings held during the design phase to assess the product or system design before production begins. DRMs can be understood as milestones within the product design process that allow the designed product to move to later stages of the process [9]. DRMs involve various stakeholders such as project managers, designers, simulation engineers, suppliers, and subject matter experts [10]. The meetings may be a formal presentation and can be conducted in person or through video calls [11]. While the application of XR technology and distributed CAD/CAE systems is a growing field, it cannot be considered an industry standard [12,10]. For this reason, the objective of the study was to find out the problems with the current widely available software, which shares the view of CAD/CAE tools through a videoconferencing application, in order ot find where the implementation of XR can add the most value in these systems [13,14].

CAD/CAE is an incredibly diverse field, making it challenging to define a one-size-fits-all set of collaborative and XR functionalities that CAE software needs [15]. Rather than attempting to encompass all CAD/CAE tools, it is more effective to study what collaborative and XR features might be needed in specific stages or tasks within the product realization process. Doing so makes pinpointing the software features required to facilitate those particular activities possible. This paper focuses on the industrial assembly workplace, particularly in the review process of digital prototypes of industrial workstations. This study will focus on DRM situations, and while they can be very diverse, the base activity is to evaluate products that are undergoing the product realization process.

This paper serves as an initial exploration into the specific needs and requirements of companies about collaborative features in CAD/CAE software with a focus on DRMs and XR for the human-centred design of industrial workstations. In the last few years, the importance of this field has been increasingly growing [16]. Organizations, including the European Commission, have been actively promoting the development of immersive training solutions for the industry through the use of, for example, AR technology in training human-robot coordination in engine assembly and VR in training welding operators platform[2]. Within the framework of the PLENUM research project, a research project involving numerous companies and universities, this study sheds light on the preferences and requirements of industry stakeholders. Focusing on the domain of industrial workstation design, we aim to outline the companies' desires and needs regarding collaborative software tailored to meet workplace design challenges in product realization. This paper investigates the requirements and preferences of the Swedish automotive industry in the context of collaborative features with a focus on XR within CAE/CAD software designed for industrial workstation design. Two distinct qualitative data collection approaches were employed to gain deeper insights into the needs and requirements.

2. Research Method

Several company visits were extended to us, encompassing two onsite visits and 15 online DRM meetings and visits, aiming to situate ourselves more effectively within the presented cases and better understand the technical and interaction requirements of these cases. Considering the sensitivity of the information being shared in these meetings, only took observational notes were taken with a special focus on how the interaction between different stakeholders and actors involved in the case is shaped and facilitated, how the current practices of the presented cases are carried out (if any) and with what type of technology; and what shortcomings and difficulties can be identified within the current practice that the inclusion of XR and collaborative features can address. The subsequent sections provide a more comprehensive overview of DRMs, as they serve as the main units of analysis in this paper.

[2]https://www.weldsimulator.com

2.1. Design review meeting observations

In the DRMs that we attended, participants followed this practice of sharing their CAD views over a videoconferencing app. The software tools used were Microsoft Teams as a videoconferencing application and CATIA as a CAD software. In these DRMs, the technical responsible for the product being reviewed shared their CATIA 3D view through Microsoft Teams and presented each of the main components of said product part by part. The product being reviewed was a fixture for one of their factories. Fifteen design reviews were attended to and observed passively over three months. These design reviews involved 13 to 16 participants, including stakeholders from different domains related to the product, such as manufacturing engineers, ergonomists, and maintenance experts.

The participants were informed of the researcher's attendance in the meetings through communication from their respective managers. The automotive company ensured the confidentiality of all data and maintained the privacy and anonymity of those involved. Therefore, the identities of participants and details of these meetings remain unrecorded. Video recordings were not a feasible option due to these privacy concerns, prompting the creation of a note-taking template as an adequate data collection method. The observation process's primary focus was pinpointing communication issues due to software limitations in remote design reviews. Whenever a new communication problem emerged, it was duly documented in the research notes that were written down in a template form. Communication problems were interruptions in the workflow that were due to software limitations. It is essential to clarify that a "communication problem due to software limitations" was only considered as such when the software tools employed to facilitate communication in these meetings failed to function effectively due to deficiencies in functionality, features, or how these features were presented to end users. For example, if an individual encountered technical difficulties while attempting to share their screen, this instance was not classified as a communication problem due to software, as the issue came from the software's failure to perform as intended. However, if someone encountered challenges conveying a specific viewpoint to the person sharing the screen, this would be considered a genuine communication problem. This template included the following information:

- Date & Time of the meeting
- Number of attendees and their roles in the meeting
- Impact of design review
- Communication problem due to software description
- Cause of communication problem due to software
- Attendees involved in the communication problem due to software

After each DRM, the researcher would revisit their notes, streamlining the grouping of recurring communication problems for a more straightforward analysis.

Following data analysis, the conclusions were presented to the participants involved in the design meetings. This presentation aimed to provide an opportunity for knowledge sharing, discussion, and corroboration of the findings. The participants actively engaged in the presentation, offering their perspectives, experiences, and insights related to the challenges they encountered during the DRM process. The participants unanimously agreed with the identified communication problems and the underlying functions that the software used in the design reviews failed to deliver.

2.2. Workshop

In describing our research activities and material, the term *case* to describe potential areas of application presented by industry partners will be used. Additionally, the term *scenario* describes the inclusion of XR technology in a given context and case (e.g. different system features, interaction modalities) as explored by the partners during the workshop. These cases and scenarios were then analyzed to identify both the user and system requirements of a potential XR solution. To capture different system and user requirements relevant to this project, a full-day workshop was held. This workshop brought together a diverse group of participants from different members of the consortium, including UX researchers, XR designers, engineers, representatives from vehicle manufacturers, and product managers. The workshop was structured around several user-centric activities and emphasized the following:

- the current state of technology within the organization and work process (whether any form of XR technology is being used or not),
- exploration of the potentials of XR technologies in designing new opportunities for interaction, collaboration and delivery of tasks and goals,
- exploration of different XR scenarios related to each stakeholder, including identifying potential functions, system requirements, and users' needs.

The participants were divided into small groups and given a set of design challenges to work on. Each group of company representatives were tasked with presenting a number of potential cases or scenarios within their organization to explore in this project. Company representatives selected and presented these cases as examples of real-world situations where the use of XR technology and solutions could improve the work process. Throughout the workshop, participants were given opportunities to provide feedback on specific features and functionalities of the product, as well as broader insights on the user experience and overall value proposition. The feedback was captured using various techniques, such as documenting the discussion and suggestions in a shared digital documenting space.

3. Results

3.1. Design Reviews Observations

In this study, the problems with the current state of remote DRMs and the potential of integrating XR technologies into the design domain was explored. To analyze the notes taken during the DRMs, qualitative content analysis was used to identify recurring communication problems. After each meeting, the notes were revised to start converging to communication problem categories earlier in the study and, therefore, have more cohesive notes throughout the study. After nine meetings, new categories stopped emerging. The last 5 meetings helped us confirm that the identified categories could accurately capture all the "communication problems due to software". Various significant issues that frequently arise during remote DRs were identified. These problems highlight the difficulties that participants encounter while trying to convey their ideas effectively. Below, the main problem categories that were encountered during the DRMs are presented.

Expressing Design Change Ideas One of the recurrent problems highlighted in our study was the difficulty participants faced in expressing design change ideas verbally, often leading to lengthy and inefficient conversations. This challenge disrupted the workflow and sometimes necessitated the use of external applications for documenting ideas.

Pointing to Specific Objects Another common issue observed was the difficulty in pointing to specific objects within complex 3D models, especially when multiple components were involved. This challenge often confused when referencing specific components, potentially hindering effective design discussions.

Requesting Specific Viewpoints: The need for specific viewpoints requested by participants and reliance on a central presenter (the person sharing the screen with the 3D model) to navigate the 3D space emerged as a time-consuming aspect of DRs. This situation caused unnecessary delays, particularly when multiple participants wanted to discuss specific aspects requiring unique perspectives.

Ergonomic Evaluation Challenges: Evaluating ergonomics on a 2D screen was challenging, as it was hard to judge if some spaces were too narrow or needed awkward positions for work. The limitations of a 2D screen impede the understanding of workstation usage and hinder the ability to express ergonomic ideas effectively.

3.2. Workshop results

In presenting our workshop results, we outline two cases presented by our industry partners, together with related XR and VR scenarios, as discussed and explored during our workshop activities.

3.2.1. XR-DRM

Within our industry partners (e.g.Volvo, CEVT), XR technologies are already being used to, for example, provide remote support through augmented reality in different stages of the product realization process. Regarding the DRM case, XR technology was seen by our participants as a technology that could provide a more interactive and immersive experience for stakeholders, helping to facilitate communication and collaboration remotely. In this scenario, XR was used to create a shared virtual space where stakeholders can collectively evaluate and engage with the design simulation in real time. Notably, one group of stakeholders may have access to a physical prototype of the designed product, such as the physical car body, while the other group can remotely access a highly realistic representation of the very same product within the XR framework to review and assess. This innovative approach was perceived as particularly valuable for geographically dispersed teams and collaborators engaged in cross-country efforts, facilitating seamless discussions and decision-making, regardless of their physical locations.

3.2.2. DRMs in VR

In a different instance, with a specific emphasis on VR, participants envisioned the potential of VR-DRM in a scenario. In their scenario, VR was seen as a tool for increasing the level of interactivity and immersion for stakeholders, thereby serving as an effective tool to foster remote communication and collaboration. Within their scenario, VR is employed to establish a collaborative virtual arena where stakeholders can collectively assess and engage in real-time discussions regarding the design simulation. In this setting, each stakeholder group is equipped with VR headsets, enabling them to immerse themselves in the virtual environment and examine the fixture simulation. The design team would lead the VR session, presenting the simulation and demonstrating how it works. The other stakeholders would review the design, provide feedback, and ask questions. For example, a stakeholder might highlight a hard-to-reach area of the assembled fixture that could pose a safety hazard to operators onsite who need to work with the fixture and car body parts.

Moreover, VR technology was seen as a way to simulate the behaviour and performance of a new product, for instance, when new fixtures and products are expected to be assembled in the factory. Such a feature would allow stakeholders to interact with the design and observe its behaviour in real time without risking the cost of deploying a wrong or defective product. This desired VR system would also allow stakeholders to experience the product in a more realistic and interactive way beyond the traditional two-dimensional drawings or models that simulation software and tools provide. Additionally, VR-DRM was seen as a way to enhance communication and collaboration during the DRM, providing a more engaging and interactive experience for all stakeholders. This was seen as an efficient approach to foster a better understanding and 'buy-in' among the stakeholders, resulting in a more successful outcome for the project.

3.2.3. XR Ergonomic Assessments & Evaluations

The CEVT team currently have access to virtual environments that include production robots, manikins, and machine parts for the purpose of conducting Virtual Build Events (VBE) and ergonomic assessments. In the existing setup, production engineers can utilize the simulated virtual reality environment to assess the feasibility of assembling parts in a real production and assembly environment. A notable feature of this system is the utilization of manikins as representations of assembly workers, which the user can control through VR controllers or a personal computer. The user in charge of the manikins can adjust the positions of these manikins in the simulated production line in VR or set their viewpoints [17] to the desired point and direction to, for example, match the manikin's grasping location. Additionally, the current system allows the user to *embody* a manikin and control its movements. These manikins can also be *steered* by a user connecting to the virtual VBE from a screen interface.

One scenario in relation to this case would be expanding the functionality of virtual environments to enable real-time visualization of ergonomic assessments for body parts of the operators. In this scenario, the envisioned XR system would allow the evaluation of the operator's postures in different conditions or highlight the reachability of products to the operator during the assembly. Such a system entails, for example, the use of colour-coded representations of the ergonomic status of the operator to denote varying levels of ergonomic suitability. Additionally, incorporating temporal aspects, such as frequency, magnitude, and duration, into ergonomic assessments was seen as a priority for an XR ergonomic assessment and evaluation system to provide a comprehensive evaluation overview of an entire workday using methodologies such as Ergonomic Assessment Worksheet (EAWS)[3]. Such an XR system was seen as an opportunity to not only shorten decision lead time but also to make the process of ergonomic evaluation faster

[3]https://www.eaws.it

through the use of XR, and finally generate dynamic ergonomic reports through realistic exploration of postures accompanied with images and videos from XR simulations.

3.2.4. Early-Identified Functions and Features

The various functions and features associated with XR design review meetings, outlined below, are a few examples that offer stakeholders a holistic grasp of the design and serve to guarantee the alignment of the final design with pertinent requirements and standards.

- The virtual environment should support different roles with different agencies: leader, internal participant, external participant, and spectator. This should be automatically assigned as default so that users do not need to put extra work into assigning different roles to different people. When a leader leaves the meeting, the leader role should be automatically assigned to someone else in the meeting.
- Objects in the virtual environment should include a hierarchy when loaded into the virtual environment, with write, read and view-only properties for different participants. This should be automatically assigned depending on the different roles of people in the meeting (leader, internal participants, external participants, spectators). Some participants can make changes only in the virtual environment, and one or several appointed users with privileged access can allow these changes to be saved into a master file.
- The VR/XR-simulation should be able to do physics simulations of the kinetics and mechanics of virtual objects, like, e.g., how a flexible part will behave depending on how it is lifted or how objects behave when being handled by multiple people at the same time (like seats, cable harnesses, engines).
- The virtual environment should allow attendees to make changes to virtual objects or presentations in real time, which are easily replicated in the original file, providing a more interactive and dynamic experience.
- The virtual environment should recognize voice commands, allowing attendees to execute commands such as: ”start recording” and ”stop recording”. This would allow a leader of a session to be able to both lead it from XR and do this without having to exit the XR session.
- The virtual environment should be compatible with a range of devices, including VR headsets, AR glasses, laptops, smartphones, and tablets, to ensure that attendees can participate regardless of the technology they have available.
- The virtual environment should provide an easy way for attendees to share files and other documents, such as meeting notes or design models.
- The virtual environment should highlight the ergonomic risks during the simulated task (using, e.g., colour coding of body parts) and offer corrected ergonomic actions. This also includes recordings of the raw data collected from the manikins and users for a post-XR ergonomic assessment (e.g., joint angles, distances).
- The virtual environment should be able to offer a degree of body language of the avatars and manikins to convey non-verbal communication that is often observed and experienced during face-to-face meetings (either online or in a physical space).

It should also be mentioned that in exploring these scenarios, participants have highlighted several risks associated with the implementation of the project. These include challenges such as stakeholders’ lack of understanding of different forms of interaction required for a virtual environment using different forms of XR equipment, potential physical harm while being in VR, varying levels of technical expertise among users, communication difficulties, and the possibility of VR meeting fatigue.

4. Discussion

In the first part of our research findings, various communication issues during remote design review meetings were observed. The second part of the study outlines how companies perceive XR-DRM as a possible solution. Regarding the specific problems people have during remote DRMs, we could argue that using different XR equipment could potentially solve most of the issues presented just because of how the technology works. If there were an ideal situation where design teams would move their design review method to XR-based design reviews, a number of the presented communication issues would be alleviated. Starting from the list:

Expressing Design Change Ideas: One of the issues observed was the difficulty in seamlessly sketching or drawing within a 3D environment, a fundamental aspect of conveying design alterations. The incorporation of 3D sketching tools or a combination of software features that allow for real-time sketching and annotation can facilitate seamless communication during DRMs. The incorporation of sketching tools that all participants in the meeting can use could greatly alleviate this communication problem. XR-based software, as suggested by Nebeling et al. (2022) [18], offers promising solutions. Incorporating a simple sketch feature in XR-DRMs could expedite the expression of design concepts and ideas. Once the participants of the DRM have reached a consensus on a design change, the possibility should be given to the attendees to visualize and replicate those changes in real-time to the original CAD file structure to be saved. A feature that was outlined as desired by the participants during the workshop.

Pointing to Specific Objects and Requesting Viewpoints: The reliance on a central presenter created some communication problems in the DRMs. XR technologies eliminate the necessity for central presenters. Participants gain the autonomy to control their viewpoints, thereby not needing a central presenter who controls the camera perspective. Moreover, participants can visually locate each other within the virtual space, enabling them to point to specific objects replicating real-life interactions. If, in specific cases, the reliance on a central presenter is important to carry the DRMs, implementing a simple collaborative pointing tool within the 3D application could be highly beneficial. Such a feature would reduce ambiguity, improve clarity, and enhance the precision of discussions by enabling participants to directly indicate and refer to specific components or sub-components. Moreover, introducing independent control of viewpoints or even decentralized control of everyone's view could be helpful in tackling this challenge. This would empower individuals to explore and control their perspectives independently, ensuring smoother discussions and reducing the need for constant intervention by the presenter. In public discussions, multiple participants could collectively control the camera, thereby facilitating focused and efficient conversations with minimal friction. As suggested from the workshop results, different roles could be assigned to the participants, giving specific read and write rights to go along with their ability to interact and manipulate the product under review.

Ergonomic Evaluations: Ergonomic evaluations in 2d screens proved to be an issue in our observations. Addressing this challenge could involve the development of tools or features that enable participants to assess ergonomic aspects within the 3D environment better, including the implementation of XR devices as visualization tools or the possibility of having virtual manikins, thereby enhancing the quality of discussions and ergonomic evaluations. Building on the workshop findings, participants advocated for an active approach to addressing ergonomic evaluation challenges. XR systems would actively provide real-time visualizations of ergonomic assessments, complete with interactive features. This active engagement would include the ability to actively adjust viewpoints, explore different ergonomic conditions, and assess the reachability of products, all in an immersive and interactive manner. It would actively enhance the understanding of ergonomic issues, leading to more efficient decision-making and active communication during design review meetings.

XR does not have to be an all-or-nothing proposition. Remote DRMs can be structured to accommodate various platforms and mediums [19,20,21]. As also suggested by the participants in the workshops, some participants may prefer to utilize XR devices, while others might rely on 2D screen-based devices, depending on the specific DRM tasks. The implementation of XR can indeed be costly, involving the purchase of new hardware and software, along with training, maintenance, and integration challenges within existing workflows. CAD/CAE tools are very diverse and they can be used for many purposes. The integration of XR and collaborative features needs to be purpose-driven, similar to this study. It is essential to find what features are critical and what XR can be integrated. Furthermore, it is important to pay close attention to how new workflows and new hardware devices can be integrated into existing ones in order to make the adoption of new paradigms easier for companies with already-developed methods and competencies.

5. Conclusion & Future Works

Implementing XR for DRM holds great promise, but it is essential to recognise that it is not a straightforward choice. It is not merely a matter of adopting or dismissing XR; it is about the manner in which this technology is integrated. XR serves as a medium for visualising and interacting with information, yet how this information is presented and engaged is pivotal for the success of the implementation. While research underscores the value of XR, it demands a deliberate strategy for its integration into established workflows. This study has offered insights into the primary issues encountered in DRMs and the industry's perception of XR. These findings serve as a roadmap for enhancing the software and hardware used to facilitate remote DRMs, helping to steer clear of potential pitfalls and ensuring a more effective and efficient future. Future work will expand on these individual categories to understand best practices in the development of features that can enhance collaboration in the 3D environment for product realisation purposes.

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