Reimagining innovation for remote, distributed teams with collaborative virtual reality

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Abstract: This paper discusses the potentiality of virtual reality to support the innovation process and to foster the innovation culture of globally distributed teams in industry. We describe learnings from several case studies of using multi- user virtual reality collaborative environment during product development process in a large multi-national manufacturing company. We discuss how to involve experts with diverse backgrounds and cultures in innovation activities through reimagined collaboration. We also discuss the benefits and limitations of VR for industrial research, development, and innovation process. The results show that multi-user VR enhances the innovation capabilities of distributed teams. Furthermore, a hybrid setup, where some participants join via desktop, also increases the level of understanding and depth of collaboration, thus fostering innovations. A hybrid multi-user platform enables larger participation of subject matter experts during the innovation process, which helps to identify and remove barriers in the implementation and otherwise improves the quality of innovations.

Keywords: collaborative virtual reality, remote collaboration, remote innovation, product development, distributed teams, remote teams, innovation, virtual reality, VR, distributed teams

Introduction

With an increased interest in Industry 4.0 interventions (Lasi et al., 2014), industrial corporations strive to advance the innovation mindset and activities internally among multidisciplinary teams (Silvestri et al., 2020). In product development innovations, physical equipment is often an essential part of the challenge and solution. However, in large multinational companies, several barriers are restricting the optimization and complicating the internal collaborative activities (Wolfartsberger et al., 2018). The primary barrier is that the access to physical equipment is often not possible, limited or requires additional travelling expenses. Therefore, the question of how to foster innovations in a global company with geographically distributed teams, where the physical equipment is an essential part of the innovation but not accessible for all, is still open. With this paper, we propose the use of *Virtual Reality (VR)* technology as an innovation driver and demonstrate how it addresses the challenges present in industry.

When working in a global dispersed setting, there are many barriers to innovation. The collaborative activities of global teams are complex, whereas existing technology tools to aid collaboration cannot yet support natural and clear communication. If you have never met your colleagues face-to-face, it might be difficult to go into the innovation mindset and find the innovation "buzz". When communicating in Teams or Zoom, concepting is not so efficient as in a shared meeting room. First, when people are meeting online, they have a tendency to multitask and not concentrate on the task at hand. Moreover, tools such as Miro and Mural are good tools for remote work and collaboration but cannot replicate *the presence of a physical equipment*. Even if the equipment or prototype is available to everyone involved or people are physically located at the same site, the physical setup can be a challenge. For example, an elevator shaft has a limited space and can, therefore, only accommodate for a limited number of people safely. Visiting this type of equipment also requires the completion of safety training and certificates, making the introduction of new people into the team a less agile process.

VR is reviewed as one of the most important emerging technologies for Industry 4.0 interventions and overall industrial development (Frank et al., 2019; Gamlin et al., 2014). Since early 90s, the large diversity of academic and industrial studies has demonstrated the usefulness and value of utilizing VR to aid industrial operations in various fields (Berg and Vance, 2017; Clergeaud et al., 2017; Guo et al., 2020; Tea et al., 2021). Not only can it provide access and interaction with virtual prototypes (e.g., 3D CAD models) in a natural manner (Berni and Borgianni, 2020; Ramírez-Durán et al., 2021; Wolfartsberger et al., 2018), but it also enhances communication and collaboration activities (Abbas et al., 2019; Bleakley et al., 2020; Wolfartsberger et al., 2020). *Collaborative Virtual Reality* (CVR), due to the possibility to provide an immersive shared working spaces for people from diverse locations, is a promising tool to address above-mentioned industrial challenges and to drive innovation (Gamlin et al., 2014; Pedersen and Koumaditis, 2020). The flexibility of CVR supports both asynchronous and synchronous collaboration and enhances the knowledge sharing and transfer among multidisciplinary teams (Narasimha et al., 2019; Pedersen and Koumaditis, 2020; Schina et al., 2016). When applied to the earliest phases of the product development lifecycle, it positively affects decision-making processes (Berg and Vance, 2017) and design for maintainability (Guo et al., 2018), which in turn potentially reduce projects' duration and associated costs.

This paper relies on learnings from three different research and innovation projects at KONE Corporation (described in Acknowledgements). KONE is a global leader in the elevator and escalator industry providing elevators, escalators and automatic building doors, as well as solutions for maintenance and modernization, to add value to buildings throughout their life cycle. KONE operates in more than 60 countries and is listed as one of the world's most innovative companies by Forbes (Forbes, 2018).

The initial idea to investigate the application of VR to facilitate the internal collaboration of departments initiated from the previous work between KONE and Tampere University where a VR system was used to foster AR development (Burova et al., 2020). The value of VR was also noticed in some KONE R&D internal activities utilizing single user VR, and VR trainings used in the company. Subject matter experts, who were involved in these activities, showed enthusiasm and desire to adopt VR technology for other use cases. These promising findings encouraged us to continue the work. In this paper, we focus on four different collaborative setups to foster innovations in product development. VR technology proved to bring value among distributed teams, to enhance the collaboration practices, and innovation capacity in all cases.

Challenges in product development innovation process

Next, we describe the practical challenges in the product development process, and objectives we want to address with collaborative VR.

The production of prototypes and products is expensive and time consuming. Furthermore, KONE's main physical products, elevators and escalators, require much space and special environment such as a shaft or supporting structures. Therefore, it is by no means feasible to have all the products available in all company locations. Moreover, entering the elevator shaft or escalator maintenance space requires special training and certificates, which all the people working with the products do not have. Yet, it would be beneficial to involve people with diverse backgrounds in the innovation process. This gives us the first practical challenge (PC):

PC1. How to enhance the innovation capability of people with no access to physical equipment?

To support agile methods and design for maintainability and design for installability, it would beneficial if people could start working with these in the early product development phases, even before the first physical prototype is produced. Which gives us the second practical challenge:

PC2. How to start innovating upon a prototype not yet existing?

At KONE, teams are scattered in different global locations in different time zones. This gives use the next practical challenge:

PC3. How to better involve people from different time zones in the innovation process?

The diverse background of employees at KONE offers many possibilities for cross- organizational and cross-cultural teams. Including a more diverse group of people in the innovation process generates new views and ideas. This gives us the fourth practical challenge:

PC4. How to involve more people in the multi-disciplinary innovation process?

We know that VR can facilitate innovation, but how about those who do not have access to VR gear? VR equipment is still quite pricy, maintaining it (e.g., software updates) requires dedication, and the use of VR requires some space. Due to these reasons, it is not possible that everyone has their own VR set, which gives us our fifth practical challenge:

PC5. How to broaden the innovation in VR beyond those who have access to VR gear?

Our studies show that we can address all these practical challenges with collaborative VR. In section 2, we describe the four different collaborative VR setups used in our numerous case studies. Then in section 3, we discuss the benefits of collaborative VR for innovation process and explain how practical challenges, described above, can be tackled with collaborative VR. Thereafter, in section 4 we describe the challenges and limitations of applying collaborative VR in industry. We end this paper with a discussion and outlook of the future.

Case studies with four different setups

We have studied how to utilize collaborative VR to foster innovations for remote, distributed teams in global settings. Again, we note that we are concentrating on innovations where *the presence of a physical equipment* is essential. In this paper, we describe findings arising from following four different setups:

Setup 1: On-site hybrid setup. With *on-site hybrid setup* we refer to a setup where one user is immersed in the VR environment using VR gear: a head-mounted display and hand controllers. Their view in VR is shown on a large display on the wall and other users are in the same room and can follow VR user's actions and discuss with them. (several sessions during 2018-2020, undocumented rough estimate 20-30 participants)

Setup 2: Asynchronous Collaborative VR. With *asynchronous collaborative setup* we refer to a system where users can visit the VR environment at any time and leave comments, pictures, and drawings for others.

(7 sessions, total of 7 participants)

Setup 3: Synchronous Collaborative VR, hybrid setup. In the *synchronous hybrid setup*, all participants join the VR session at the same time. Some participants join with VR equipment and are immersed in the VR environment. Some participants join over a video conferencing tool, where the VR users and their view in VR is streamed. (12 sessions with 29 participants)

Setup 4: Synchronous Collaborative VR, all-in-VR setup. In the *synchronous all-in-VR setup* all participants join the VR session simultaneously using VR gear, and they all are immersed in VR environment. (6 sessions with 28 participants)

Table 1. The summary of industrial studies (N = Number of experts involved)

Setup	Industrial Scenario	Experts involved	N
Setup 1	Maintenance development, design for maintainability and maintenance training	Maintenance methods developers, product engineers, risk assessment experts, XR training specialist, and training experts	NA
Setup 2	Collaboration in the pipeline of maintenance method development and technical documentation creation	Maintenance method developers and technical writers	7
Setup 3	Collaboration in the pipeline of maintenance method development and technical documentation creation	Maintenance method developers and technical writers and illustrators	29
Setup 4	Collaborative review of technical documentation and risk assessment, Collaborative machine room planning for high-rise buildings	Technical writers, maintenance method developers, risk assessment experts, project engineers, construction project managers, installation supervisors	28

Experiments with the first setup were carried out in two different projects. In the other project, the agile lean start-up method was used to learn quickly the constraints of VR use for industrial use. At that time, in the company internal project, documenting the number of participants was not considered important and only learnings from user tests were recorded.

Another thing worth mentioning is that Table 1 presidents the number of participants in *formal user tests*. In the company, collaborative VR use sessions have been demonstrated and discussed in different occasions to numerous people, and these learnings (e.g., user comments) have been used when developing ways-of-working for collaborative VR. In addition, a large number of industrial experts have participated in ideation phases in the iterative development. Furthermore, some questionnaires and interviews were carried out with a *wider audience* than the user tests participants reported in Table 1. A rough estimate is that over 100 people have provided their input at some point on how to utilize collaborative VR as an innovation platform during product development.

Benefits of VR for innovation process

Let’s review how collaborative VR can tackle the practical challenges described in the previous section.

We can create a digital replica, a 3D model, of a physical product, equipment, or component, and we can also create a 3D model of a not-yet-produced prototype under design. These 3D models can be imported into the VR environment for further ideating, inspection, and discussion. Our studies with collaborative VR clearly demonstrate that we can enhance the innovation capability of people with no access to physical equipment, and that collaborative VR also enables innovating upon the not-yet-produced prototype. The two first practical challenges (PC1, PC2) can be tackled with all the four setups (Setup 1- 4). As one of the participants commented: *"Users from different departments do not need to cooperate face to face. They can work together by using VR online." (Setup 2, questionnaire).*

Our studies show that the third practical challenge (PC3) can be addresses with the asynchronous collaborative setup (Setup 2): *"[It is] easier to collaborate especially remotely. [It] can give people a better understanding in a safe and controlled environment." (Setup 2, interview).* People from different time zones can use the VR environment when it is convenient for them and leave notes for other users. Asynchronous collaborative setup (Setup 2) also allows to involve more people in the multidisciplinary innovation process (PC 4) as people can visit the VR environment during a time convenient for them (PC3). This also facilitates the sharing of VR resources, and one set can be utilized in turns by many different experts (PC5).

Yet, as not all people have access to VR devices, we have investigated hybrid setups where some participants join with VR gear, and others via video conferencing application (e.g., Teams). Our studies show that hybrid setups (Setup 1 and Setup 3) enhance the innovation capability of all participants and, thus, we can broaden the innovation capacity beyond those who have access to VR gear (PC5). All in in all, with hybrid setups we can include more people in the multidisciplinary innovation process (PC4).

Now, let's examine the benefits of collaborative VR in more detail.

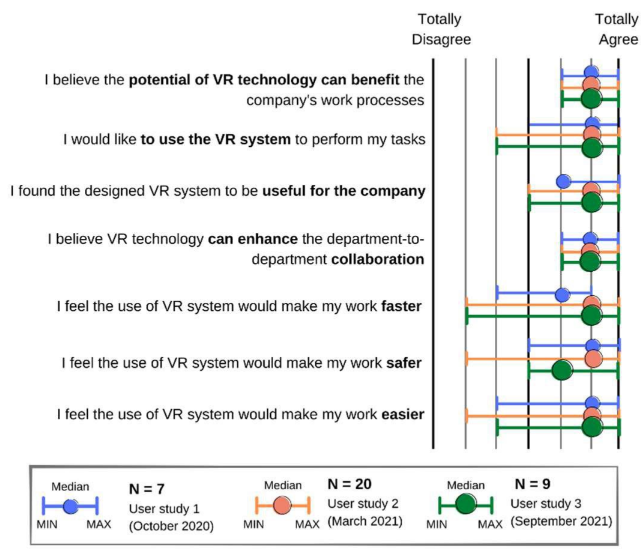

Figure 1. Perception of VR technology based on setups 2–4

Figure 1 presents the combined results on the perception of VR among subject matter experts: the survey was iteratively utilized in the case studies from Setup 2 to Setup 4 to gather the changes of perception during the adoption of VR among different use cases and teams. The figure illustrates an overall positive perception of VR technology since the beginning of the adoption as well as an increase in the perception, related to the continuous development of the system based on domain expert's involvement in the development process. In all three iterations, experts believed that the potential of VR technology can benefit the company's work processes and can enhance the department-to-department collaboration. Similarly, all experts would like to utilize VR to perform their work tasks; the majority also believed that VR system would make their work faster, safer, and easier. As one participant commented: *"[It can be used]to improve the communication and have high-efficient meetings" (Setup 3, interview)*.

Our studies show *enhanced collaboration* with all the four different setups. In the synchronous collaborative setups 3 and 4, the VR users reported *"a strong feeling of being together" (Setup 3, observation)*. Our studies show that all five setups provide a *better means for communication* than traditional communication methods (emails, shared notes, video calls, etc.). For example, participants noted: "*[VR would] improve the communication and [we can] have high-efficient meetings"* (interview, Setup 3) and *"having different users to learn about the 3d models will be useful - You could teach and having this available in our department would open opportunities to learn" (Setup 2, survey).*

Collaborative VR also *fosters innovative thinking*. For example, in Setup 1, the participants invented a new, better way of performing a maintenance procedure. Furthermore, in Setup 2 one expert commented that "*VR enhances the innovation mindset of employees and improved collaboration among members." (Setup 2, survey).*

VR is, by nature, an immersive environment, and it does not allow multitasking (checking emails, chatting, etc.) when using the VR gear. Therefore, the VR users focus with their *full attention* to the matter at hand. This concerns *the VR users* in all five setups.

Including VR reviews in the early phases of product development process (PC1, PC2) enables a better design for maintainability and for installability. As one user put it, *"VRE [virtual reality environment] would help at the concepting level" (Setup 3, observations).*

VR contributes to occupational safety in two ways. It helps in developing safe solutions, and it is a safe environment for testing. *"Safety. This is the most important. Also using VR can make work processes more convenient."* It also enables several people to enter a tight and cramped space, which is not possible in the physical environment (PC4). In addition, moving around a large equipment is convenient and safe in VR. As noted by a participant, "*Large equipment is often hard to see in real, especially with a group of people. VR will enable this, safely." (Setup 2, survey)*

In a multi-national company, the innovation potential is scattered to different locations. Including global participants in product development innovation requires tools and practices. Collaborative VR is one tool that can be used to increase global participation and cultural inclusion, in a sustainable way (PC1, PC3, PC4, PC5). Users clearly saw benefits with this: *"No site visit needed if you can see the same in VRE [virtual reality environment]. Would get rid of the travel time." (Setup 3, observation).* Collaborative VR is also an efficient knowledge sharing tool (PC4). As one of the subject matter experts put it: *"Good enabler for enhancing prototypes, demos, and sharing information. It can be very beneficial. Implementing collaboration in long physical distance." (Setup 3, observation).*

Challenges and limitations in adopting VR

Several challenges were encountered when applying collaborative VR for industrial use as part of the product development process.

Some of them where typical human–technology interaction (HTI) and user experience (UX) issues. For example, the use of hand controllers required getting used to them, and still, they did not feel comfortable and did not fully support maintenance type of actions inside VR. Also, text entry within VR is clumsy, and users found text editing especially difficult. Luckily, techniques such as automatic speech recognition (ASR) make it possible to enter text efficiently, freeing both hands and eyes.

Furthermore, the work of a maintenance method developer, for example, requires jumping between devices, i.e., VR gear and PC, which is not fluent. For occupational safety reasons, we assign a person to make sure that the person using VR gear does not hit the wall or other obstacles and does not get tangled in the cables. Naturally, from the resourcing point of view, this is not very efficient.

The use of VR requires some empty space, the ideal size being from 3x3 meters upwards. Tracking used on VR devices is easily disturbed by reflections from glass. Therefore, meeting rooms with glass walls or windows need special curtains. The effective use of VR devices would mean, for example, enabling hybrid use (Setup 1, Setup 3). This will further increase the space requirements. All in all, it might be difficult to find a suitable space in the modern offices where space utilization is maximized.

Although many papers demonstrate real cost benefits from adopting VR for industrial use (Badamasi et al., 2021; Guo et al., 2020; Mak et al., 2020), the price of devices still appears to be too high for many decision makers in industry. This makes it hard to quantify the actual cost benefits of VR integration (Dücker et al., 2016) .

Naturally, there are challenges with technology acceptance. In addition, the use of VR requires some digital skills (e.g. updating VR software). Therefore, it might be difficult for some people to adopt VR as a part of daily work if you are used to working with a wrench and screwdriver and handling physical devices.

One of the biggest challenges in adopting VR as a part of the process is the practical problems with 3D file format conversions. Although CAD software has an option to export in a VR-compatible file format, it is not that straightforward in practice. For example, the number of triangles need to be reduced in order for the model to run in VR, and sometimes textures are lost. Often manual work is needed, and some "tricks" like exporting from CAD software → editing manually in other application → exporting to VR format → uploading to VR Software → editing again → exporting again, and so forth.

Sketching in VR is difficult, and this is also a practical limitation. Even though tools have been developed for sketching purposes, using them with the controllers does not feel natural in most cases. The simplicity of using a pen to draw on a whiteboard, an action performed constantly in meeting rooms, is surprisingly difficult to imitate in VR. Further development is, therefore, needed for tools and sketching practices in VR.

Sometimes there is still a mismatch between the virtual representation and reality. As one of the subject matter experts put it, *"It is only a simulation of the real world and can give false impressions to people with no experience of the real environment and components etc." (Setup 4, observation).* The expectations based on VR versus the reality can be either higher or lower.

There are also limitations for the number of people in multiuser VR and audio issues (external audio). One of the main features of VR is its spatiality, which also means that the audio is spatial. Even though this can be a very useful feature for, for example, studying how audio-related solutions work in practice, it can also create major challenges. In large multi-user VR environments people need to be close to each another in order to communicate. Similarly, if people want to look at a small object at the same time, they need to gather around that particular object. These are examples of how mimicking real life could be disadvantageous. Fortunately, there are solutions for these. For example, we have found it sometimes useful to utilize separate, non-spatial audio communication channels instead of the built-in auditory communication means of VR environments. Also, tools such as remote cameras can be highly efficient for looking at the same objects from different locations.

Real versus virtual worlds: when should we utilize real-world correspondence and when is it not feasible? This is one of the fundamental questions when utilizing virtual worlds. Based on our experiences, in some scenarios such as installation and maintenance tasks in industrial context, it is crucial to have a one-to-one match with real world tasks. Yet, realistic rendering (i.e., realistic looking materials on components) is not needed for testing maintenance methods. Furthermore, like in the case of spatial audio, realism might be even disadvantageous. Similarly, it is not efficient to mimic a real-life meeting or teaching habits in VR – for example, instead of making PowerPoint presentation for virtual reality we should find more clever ways to utilize VR. Moreover, instead of sitting in a virtual meeting room or a classroom, we can face each other and communicate in totally different ways. Further research is needed to find good ways to realize the true potential of VR.

These topics raise another important question: How can we make VR better than real life? As said earlier, transferring real-life practices into virtual worlds is not often the most efficient solution, and it can be even counterproductive and provide a worse user experience when compared to the physical world and reality. On the other hand, if we can find novel ways to accomplish things in VR, it can give us super powers that transform even the most boring tasks into something that is fun and efficient!

In many circumstances we are not able to work at the same time with our colleagues, especially in a multi-national context where people are located in different time zones. There is a clear need for asynchronous communication. This is a normal routine in globally operating company, especially when the work is carried out in global agile end-to-end teams. There are also other benefits coming from digital environment. For example, when we work in a physical world, we cannot freeze or baseline its state easily. However, in VR we can always take a snapshot of the virtual world and allow other people to visit it later on. This can have numerous benefits, for example, when new products are designed. In such cases, people can see the design in its various stages, and, for example, try out the product in its current state and leave comments.

One of the key aspects in VR is its "built-in" capability of capturing (logging) user interaction in numerous ways. Most importantly, the user location, orientation, gaze direction (and when gaze trackers are used, also accurate gaze data including gaze paths etc.), hand (and sometimes other body) movements can be captured easily. This allows for an in-depth analysis of not only what users are doing but also how they are doing tasks in VR. This generates rich possibilities to measure, for example, if users are performing their tasks safely and efficiently (Burova et al., 2020).

Discussion

As our four cases demonstrates, there are different ways of utilizing collaborative innovations. With hybrid and asynchronous setups one can expand the benefits of VR to also non-VR users and involve a more diverse group of people in the innovation process during product development. Yet, it is very important to remember that VR is not the holy grail that solves all problems. Therefore, it should always be considered when to use VR as an innovation platform, and when some other platform is more suitable.

When wisely adopted, collaborative VR supports sustainable innovations in all three dimensions of sustainability: the economic, environmental, and social, in the context of remote, distributed teams in product development. Let's review these more closely.

First one is obvious: collaborative VR reduces the need for travelling. It also makes it possible to share knowledge and involve people from locations where people do not have the physical equipment available. Therefore, in a multi-national company, VR provides more equal opportunities for career growth, facilitates for the inclusion of viewpoints from different geographical locations and, thus, enhances equality across different locations. All in all, it increases the inclusivity inside the company.

When VR is used in the early phases of product development or in the planning phase for constructions, it helps to avoid mistakes and, thus, excess material or wasted prototypes are also avoided.

VR has potential to enhance product development in various ways. Moving a part of the product development processes into a digital format, in this case using collaborative VR as an innovation platform, leads to a faster product development cycles, and faster time to market. When design for maintainability and design for installability is started in the early product development phase, it is easier and cheaper to make design changes. This leads to better products and cheaper life-time cost.

Most importantly, making experiments in VR is faster, cheaper, and it is easier to include a diverse group of people in ideating which improves the innovation capacity of the company. However, collaborative VR is not "an innovation machine", and it is only as good as the people using it.

Outlook

What comes in future and how would emerging technologies, such as VR, affect the industrial operations? One thing is sure: there is lot of buzz on technology side: Facebook just announced that it will become a Metaverse company, Magic leap is entering into the enterprise market with AR glasses, and Varjo made photorealistic virtual teleportation come true, just to mention a few recent news.

No one can surely predict the future. However, there is a strong indication that the traditional ways of working will be shifted. Combined with other evolving technologies of Industry 5.0, VR brings the potential to optimize processes and deliver novel ways of co- creation and innovation practices. Artificial Intelligence (AI) and synthetic media would be able to replace and assist in complex and routine tasks, giving more time for and boosting human innovations. Automatic translation and interpretation would significantly improve communication among global multicultural teams, while the flexibility of VR would ensure the existence of shared working spaces and advanced tools for generating digital content and development of novel solutions. The opportunity of re-using existing virtual environments and aligning them to suit various use cases proves the usefulness of developing industrial VR-based solutions. Furthermore, the power of simulations, supported with the data from real capture would strengthen the predictions and analytics for decision making, while integration to VR analytics would uncover previously unnoticed issues.

Overall, the adoption of innovative technologies to existing working practices would foster the sustainability of industrial operations, improve the quality of collaboration practices and yield better innovations.

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ARPOC was a KONE internal R&D project, focusing on XR use in elevator maintenance in 2016-2019. Within this project we experimented the use of VR, and collaborative VR for maintenance development, design for maintainability and maintenance training, among other things. We share some of the project findings in this paper. We thank all our colleagues who contributed to this project.

KEKO is a Business Finland funded Smart Ecosystem project (KEKO). In this paper we share our experiences based on one of KEKO actions, collaborative VR for machine room planning for high rise buildings. We thank all our colleagues and partners who contributed to this work.

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As the result of HUMOR project activities and based academia-industry collaboration framework (Burova et al., 2021), COVE-VR platform was designed and developed. The COVE-VR consists of two virtual spaces and ten virtual tools to support the collaboration of departments, involved in the pipeline of method development and technical documentation creation. The COVE-VR (or its predecessor) was used with all the setups. We thank all people who contributed to the platform development and provided insights on how to link the platform design with actual industrial needs.

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Glue collaborative VR environment by Glue Collaboration was utilised with Setups 1 and 3 (Glue). We thank Glue Collaboration for their support.

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