

Article

Enhancing Remote Industrial Training Experiences with Asymmetric Virtual Reality: Experiences, Tools and Guidelines

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Featured Application: This paper presents a user study with industrial maintenance and installation experts of an elevator company. The results confirm that the remote training experience can be enhanced with asymmetric VR training.

Abstract: Training in virtual reality (VR) is a valuable supplementing tool for advancing knowledge transfer that results in increased efficiency and accuracy of technicians in fieldwork. However, COVID-19 pandemic restrictions made it impossible for VR training centers to operate on a full scale, forcing traditional face-to-face learning sessions to become remote. In this article, we investigate the asymmetric use of a VR training solution—among devices with different levels of immersion and control—to enrich the content of remote training sessions. The VR in this case can be seen as a source of visual and other contextual information to advance the effects of situated learning and enhance knowledge transfer. To evaluate this approach, we conducted a remote user study with ten industrial maintenance and installation experts. We also introduce the “Research Panel” tool to gather reactions of learners during the remote training session. The expert user study results demonstrate the usefulness and relevance of asymmetric VR to improve remote training sessions and other application industrial scenarios, while the “Research Panel” data provided detailed insight into the session flow. Building on the qualitative findings, we present design guidelines to aid the adoption of asymmetric VR in the industrial context.

Keywords: virtual reality; VR; asymmetric VR; training; remote training; industrial maintenance; installation; fieldwork training; knowledge transfer



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1. Introduction

The technologies of the mixed-reality continuum [1], such as virtual reality (VR) and augmented reality (AR), also known as technologies of extended reality (XR), have a lot to offer to the field of industrial maintenance, assembly, and installation [2,3]. By blurring the borders between real and digitally created content, XR can advance, optimize and increase the efficiency of industrial operations, influencing lower costs and higher revenues [2,4]. The adoption of emerging technologies is a critical factor to advance existing industrial practices to compile with Industry 4.0 interventions [4]. Indeed, the flexibility of XR presents novel methods to aid, enhance, and shift traditionally accepted ways of working [2,5]. Considering rapid digitalization and the development of artificial intelligence and the Internet of Things, the adoption of XR would not be extremely complex or expensive, compared to the potential benefits it brings to the industry.

One of the greatest examples of how XR technologies can be applied in industrial settings is to facilitate training. The benefits of performing industrial training in VR have been explicitly demonstrated by the extensive body of research on the topic [6–8]; it positively affects the effectiveness and accuracy of maintenance technicians while minimizing error rates. Further, it advances the transfer of knowledge and skills by improving situated learning and spatial understanding [9,10], since training happens in a simulated but still realistic context, which would help technicians to become familiar with their work environment without physically attending it. Even though training in VR would prepare technicians for fieldwork, it still should be reviewed as a supplementing way of training rather than replacing [11].

With the recent restrictions on the social gathering, forced by the COVID-19 pandemic, many industrial processes were forced to become remote. Among others, training and learning activities of industrial maintenance technicians, which were usually arranged as physical gatherings in training centers equipped with simulators, test elevators, and VR equipment, during the pandemic were arranged remotely via Microsoft Teams, while the access to training centers was physically restricted around the globe. This rapid jump towards remote ways of living and working caused a critical change in educational activities of industrial maintenance and assembly trainees with a possible reduction of educational effects. To minimize the negative effects of forced remote learning, the existing practices should be reconsidered and adapted to the current world conditions, using the flexibility of XR technology. Despite the fact VR cannot yet be accessed in an immersive way by every trainee (considering the low spread of technology and its relatively high price), VR-based educational content can still be utilized for learning purposes to advance remote learning sessions and positively influence situated learning. This can be facilitated by applying asymmetry to VR usage—meaning making virtual environments accessible via diverse technologies with different immersion and control levels.

Asymmetric VR, which originated from studies on telepresence [12], evolved into a body of research, exploring the asymmetry of experiences between various groups of users, accessing virtual environments via different end devices [13–15]. Multiple studies demonstrated that, even in an asymmetric setup, VR enhances collaboration, communication, and learning in both co-located and distributed settings [9,16–19]. The benefits of asymmetry are especially visible when compared to collaboration over traditional conferencing tools in the example of global teams, where the interaction is limited to writing, chatting, or participating in calls with limited verbal and non-verbal communication. The asymmetry also expands the scalability of VR technology and participation, allowing a wider circle of users to be included in the collaboration and learning processes without relying on costly and complex setups [20] using head-mounted displays (HMDs).

Based on the potential mentioned above, we present an approach of utilizing a VR training system asymmetrically as a part of a remote training session, as shown in Figure 1. In our case, streaming a video feed from the VR training system to a traditional conferencing tool (such as Microsoft Teams) as a part of the training process may enrich the educational content and introduce the context, which would further enhance the effects of knowledge transfer and situated learning. Furthermore, such an approach allows for performing activities impossible in reality, such as inviting a larger group of learners to the virtual space, which simulates dangerous and hard to physically visit locations in reality (such as an elevator shaft, which, depending on its size, may accommodate two to four people). Even though learners would not be able to experience the virtual space in an immersive manner, it still would increase their understanding of proximity, maintenance, installation, and occupational safety procedure flow. Thus, VR content provides a convenient alternative in numerous cases where recording high-quality videos in a physical location is impossible due to safety concerns.



Figure 1. Asymmetric use of VR training system while in a remote training session via Microsoft Teams.

To investigate the matter, we performed a case study in close collaboration with academic and industrial researchers from a global elevator manufacturing and maintenance service provider (KONE corporation). Together, we conducted extensive piloting, followed by a remote user study with ten domain experts in maintenance and installation, recruited from the company’s employees. Our study addressed the following research question:

RQ: How should asymmetric VR be applied to facilitate remote training sessions and improve knowledge transfer?

To understand how experts experience and perceive the use of asymmetric VR as a part of the remote training process, we collected subjective metrics via online post-survey and the “Research Panel” tool. The tool was specifically designed for the user study to collect instant reactions of learners during the training process, which can be further synchronized to the training session timeline, allowing in-depth investigation of the dynamics and flow of the session. The contributions of this study are elicited based on a qualitative expert-based study of using asymmetric VR for remote industrial training purposes, which has not been studied previously. This article’s contribution lies in (1) exploration of cost-efficient asymmetry between VR platforms and traditional conferencing tools in industrial settings, which elicit several beneficial industrial scenarios for further usage, and (2) design guidelines, which provide instructions and factors to consider when designing asymmetric usage of VR systems. As an outcome, our work suggests a novel way of utilizing VR-based training, which potentially would not only increase interest and initiate discussions around the topic of asymmetry but also positively influence the overall understanding of the value of XR technologies for the industrial sector and boost its adoption.

The article is structured as follows: Section 2 presents the background and related work, detailing the aspects of asymmetric VR, followed by information on industrial training in VR and related learning theories. Section 3 describes the industrial context and industrial training practicalities, followed by the details of the performed industrial cases study—including asymmetric set-up, data collection, and analysis methods. Section 4 presents the results of the case study, building on the analysis of data from “Research Panel” and digital surveys, and summarizing experts’ subjective perceptions of asymmetric remote VR training. Section 5 discusses the benefits of asymmetric VR, presents relevant industrial scenarios, which may benefit from asymmetric set-up, and compiles all the study insights into a list of guidelines on how to apply asymmetry in the industrial context. Section 6 concludes the article, presenting our final thoughts and the contributions of this case study.

2. Related Work

The adoption of VR, which is an integral part of Industry 4.0 intervention [4], holds unlimited potential for industries and businesses. An extensive body of research on the application of VR in an industrial context [2,4,5] demonstrates the potential to enhance and shift existing practices. Indeed, the flexibility of simulations and interactions in VR offers a

range of benefits to the training and learning of maintenance technicians [6–8], providing them with safe and novel ways of practicing.

With world-changing pandemic restrictions, the use of VR as a part of industrial processes became limited. For instance, at the beginning of the pandemic, VR-based training was available in 20 KONE training centers around the globe. While COVID-19 restrictions varied locally, all training centers were in lockdown from April to the beginning of August 2020 and continued to have policies for maintaining, e.g., 50% capacity on the premises and restricting travel, expanding all way to 2021. In January 2021, eight training centers reported being in lockdown, while the traveling restrictions continued to affect the access to VR devices throughout the year. Moreover, the utilization of a single HMD by many users was reconsidered and required special measure, e.g., disinfection or protective elements, similar to masks. Despite being present on the market, due to high costs and lack of infrastructure, VR equipment is still not widespread to the extent as smartphones—people rarely own VR equipment. In addition, because of the shortage of electrical components during the pandemic, it was difficult to order devices, for example, in India.

As a response to mentioned challenges, the scalability and accessibility of *asymmetric VR* become a promising approach to investigate—especially the use of asymmetric VR as a way to advance remote training sessions and provide visual contextual information, which has not been explored previously. Important to mention is that asymmetry, although a necessity during pandemic restrictions, has its clear benefits in the post-pandemic world. In this section, we firstly present the concept of asymmetry in VR and then discuss the use of VR for industrial training and describe associated benefits based on the industrial case.

2.1. Asymmetric VR

Asymmetric VR is a relatively novel branch of VR-related research that explores the use of VR among devices of different immersion and control levels, focusing on the experiences of non-HMD users [13]. The asymmetry occurs when users access the same virtual environment or system using a different technology (for instance, HMD and a desktop-based user interface), which cause uneven experiences and difference in interactions and control. The term “asymmetry” took its roots from studies on telepresence and telecollaboration [12]—when symmetric access to virtual environments was reconsidered by virtually recreating a real environment and allowing remote participants to access it. However, in recent years, the research on asymmetric VR was focused on the use of VR for collaboration in co-located settings [13–15,19], whereas distributed asymmetric VR gained less attention and was mentioned as a cross-platform multi-user VR [14]. Several studies have investigated the appliance of VR in combination with other technologies of mixed-reality continuum or wearables [15,21–23], contributing to a better understanding of immersion, presence, and social interactions of non-HMD users. For example, Zhang et. al. [24] presented a low-asymmetry interface, which increases the presence and immersion of non-HMD users by providing a first-person view and realistic movements in a virtual environment based on a portable tracking device. Another study [15] proposed to increase the presence and enjoyment of non-HMD users with floor projection, additional mobile displays, and positional tracking.

Furter, Ouerson and Gilbert [14] attempted to characterize how co-located VR asymmetry occurs and how it affects collaboration building on the incorporate theory from the Computer-Supported Cooperative Work (CSCW) field. Their article presented a composite framework of co-located asymmetric VR (CAVR) and introduced the dimensions of asymmetry: three technology-related (transportation, spatial co-presence, informational richness) and two interpersonal experiences—related (team interdependence, and balance of power). Another study [9], which may be applied to distributed asymmetry, defined the degrees of asymmetry as low, medium, and high and suggested defining it based on the interactivity of non-HMD users (also referred as non-VR users). The users of asymmetric VR, therefore, are divided into an actor, who perceives the space through an HMD, and an assistant,

who participates in a less immersive manner, while the interactivity of the assistant, which ranges from direct control to absence of control, defines the degrees of asymmetry.

The topic of collaboration via asymmetric VR gained increased interest during the COVID-19 pandemic's remote work enforcement [25], leading to the exploration of asymmetry in distributed settings [16,18,19,26,27]. For example, Lyu et al. [19] presented a scalable cross-platform prototype that allows communication interactions between a single VR user and multiple non-HMD users on a standard web browser. Further, Reski et al. [18] compared experiences of VR and non-HMD users in a similar setup in the context of immersive analytics and reported overall good user engagement, usability, and collaboration flow despite asymmetry. Another study [16] presented a low-cost approach to the asymmetry between Microsoft Teams and multi-user VR, demonstrating positive effects on collaboration between multidisciplinary teams and enhanced spatial understanding of non-HMD users. Despite the asymmetric VR showing the capability to advance distributed and co-located collaboration, there is a lack of understanding of how it affects learning [28], which results in no clear understanding of how to apply asymmetric set-up for industrial VR-based training to ensure beneficial effects on learning outcomes.

2.2. Industrial Training in VR

Industrial maintenance, assembly, and installation is one of the largest application fields of VR and may greatly benefit from adopting VR technologies. The major application is split into two areas: (1) pre-job training and (2) on-site support [2]. VR-based pre-job training is a well-studied matter, which demonstrates positive effects on the performance and accuracy of maintenance technicians coupled with a decreased error rate and training time [6–8,20,29]. A study by Winther et al. [11], for instance, demonstrated that after 20 min of training in VR, participants were able to perform maintenance operations over a real-world dosing pump. Nevertheless, their study showed significantly better performance of traditional hands-on training methods (pairwise and video training) over VR training, indicating that VR training should supplement, rather than replace, traditional methods.

From the perspective of elevator manufacturing and maintenance companies, such as KONE, and supported by existing research in the field, VR training has clear benefits for the industry. First, it provides a safe environment for learning safety-critical tasks [2,30]. The learner can also repeat the task several times if needed, opposite to, for example, real-life installation tasks, which can be conducted only once per installed product. Another explicit benefit of VR training is the possibility of practicing the installation and maintenance of a brand-new product that has not been physically built anywhere yet, which results in the installers being better prepared for the first installations. Further, VR training modules can also replace expensive physical simulators that are only available in a few locations and require learners to travel—whereas the substituting VR training modules are available everywhere with the VR sets. Additionally, many elevator components are large and heavy (e.g., a big motor weighs several thousand kilograms), thus making real-life maintenance tasks physically demanding, whereas VR training is physically light and requires no additional physical workload.

The efficiency of industrial training is linked to the concept of training transfer—the ability to transfer and apply gained (during the training) competencies, knowledge, and skills to the real-job task. The quality of training transfer depends on two factors: learner characteristics and intervention design and delivery [31]. The concept of transfer overlaps with existing theories, present in the educational domain—for instance, with deep and meaningful learning. Deep meaningful learning, defined by Mystakidis as “the higher-order thinking and development through manifold active intellectual engagement” [32], where meaning is created based on concept association and pattern recognition, comes from the combination of deep learning and meaningful learning approaches. The use of technology can advance deep meaningful learning activities when used as a base for teaching and learning strategies to support discussion, cooperation, and knowledge creation [32], e.g., affecting intervention design and delivery of transfer via technology.

The strength of learning in immersive virtual environments comes from gaining specific context-sensitive knowledge in simulated spaces, which enables active learning [31] and helps to transfer and apply gained skills to real-life situations [9]. This, in turn, advances both content relevance and practice, and feedback variables of intervention design, increasing the quality of training transfer [31]. In the context of industrial maintenance and assembly, such processes may be also referred to as a knowledge transfer from experts to learners. VR, due to realistic simulations and experiences, enhances the effects of knowledge transfer from the virtual world to the real as well as positively affects situated learning by immersing the learners in a virtual space in which specific knowledge can be acquired [9]. The article by Gasparello et al. [33], for instance, demonstrated this approach in the industrial study, where a real-time stereoscopic 3D CAD model rendering was utilized to advance a remote training session and positively affect the perception and comprehension of complex 3D objects to assemble/disassemble.

However, despite VR offering a flexible means for e-learning, the ways of facilitating deep meaningful learning activities within VR are barely explored [28], not to mention the additional concerns of asymmetric VR. Therefore, it is essential to investigate if the lack of presence and immersion of asymmetric VR would reduce the effects of situated learning. A study by Drey et al. [17] indicated equally well outcomes in learning when comparing symmetric and asymmetric use of the VR pair-learning application. However, the effects of asymmetry are hardly explored when it comes to knowledge transfer in the industrial context from experts, being actors, to learners, being assistants. A similar concept from the context of education and marketing, known as “knowledge demonstration”, was discussed in the article by Horts and Döner [34], pointing out that transfer-richness and high interdisciplinarity are essential factors to facilitate knowledge demonstration and suggesting the use of collaborative VR asymmetrically as one of the potential scenarios to investigate the matter further. Another study [27] introduced the role of the VR guide, especially for distributed asymmetric VR setups, which would improve the perception of virtual environments for HMD users.

To summarize, the COVID-19 pandemic caused several restrictions on using VR training centers [10,35], and forced the change from traditional face-to-face to emergency remote learning. This rapid shift demonstrated the need to advance the quality of remote learning training experiences, aiming to achieve deep and meaningful online learning practices [36]. One of the possible solutions to address this is to apply asymmetric use of the existing VR-based training system as a method to visualize context and context-sensitive information, related to training, as suggested by the preceding study [16]. Despite there being evidence that VR can supplement remote training and educational processes [10], such a scalable and non-immersive asymmetric approach still requires verification of the learning experience.

3. Materials and Methods

The industrial case study, described in this article, was conducted as a part of collaborative work between academic and industrial researchers as a part of the HUMOR [37] project. In this section, we first provide the context by detailing the VR training process and its specifics. Next, we describe the performed user study, including asymmetric VR set-up, the user study procedure, data collection, and analysis methods.

3.1. KONE VR Training in Brief

KONE [38] is a large, global manufacturing and service company providing people flow solutions, which produces and maintains elevators, escalators, and automated building doors. The company has circa 60,000 employees, roughly half of which work in the field.

KONE, being an early adopter of VR technologies, has been using it in technical training since 2017. KONE VR training, which is utilized in over 30 locations worldwide, is aimed to complement the learning experience and not to fully replace hands-on training (see also [39]). VR training consists of modules that are usually 15 to 30 min long sections of

installation or maintenance methods, where the learner can perform the needed technical tasks, including, e.g., drilling, measuring, setting parameters, and making safety checks. Modules visualize and make the products tangible, but also show innovative ways of training employees. According to an internal feedback survey at KONE with escalator installers (carried out in November 2021), VR training was rated as the second preferred method to learn new installation or maintenance methods, just after the physical simulator.

In practice, VR training requires VR equipment (consisting of a computer, VR headset, and hand controllers), room for the equipment, a trained VR facilitator, and time from both facilitator and learners. A learner never uses VR alone, but a VR facilitator is used in all training to ensure the safety of the learner while using VR gear. One facilitator's responsibility is to guard the learner so that they do not collide with furniture or walls and provide quick assistance in case of nausea or dizziness. A VR facilitator is often a trainer who has combined the VR modules as part of a training course.

At KONE, co-located asymmetric VR training was already utilized pre-pandemic, as elevator or escalator training courses are seldomly one-to-one sessions. One learner was inside VR, while the trainer facilitated the session and other learners followed the VR view from a bigger external screen. Learners then took turns using VR, and the trainer could point out important aspects of the learning material as well as discuss with the learners.

3.2. VR Training System—A Technical Overview of the Asymmetric Setup

The VR training software module used in this case study was created on the Upknowledge Learning Engine platform [40]. The training module was developed in collaboration with Upknowledge and KONE experts to cover specific safety-related learning needs. The development process started by identifying the learning need and having a kick-off meeting with both parties to decide upon essential steps to be included in the training material in a way that ensures the best possible learning experience. Professionals involved in the process were trainers, domain experts, and VR developers. Content of the training module was iterated based on the comments provided by the domain expert and approved by stakeholders before publishing.

The module was instructionally designed to provide the basis [41] for learning safety procedures and the operation of safety-related work aids during elevator installation, maintenance, and modernization when using man riding hoists. For the duration of the training module, the learner is immersed in a virtual environment, based on an accurate 3D CAD model that can show the elevator in all installation phases and guide through an elevator installation work process, as well as maintenance procedures. The learner moves around the elevator shaft, performing the key safety-related actions in various phases of the elevator installation and maintenance. They pick up and operate safety devices and tools, as well as follow animated demonstrations of the operation of the safety-related elevator systems.

The platform features support multiple usage scenarios for maintenance training, which can be performed in self-study or asymmetric set-ups. For self-study set-up, the module features a narrated virtual trainer that guides the learner through a pre-scripted sequence of tasks and demonstrations. For the asymmetric set-up, a VR guide (trainer or training assistant) can take the place of the learner and demonstrate performing the tasks, while the learners are observing it over a video feed, streamed to any traditional conferencing tool (such as Microsoft Teams). The video feed resolution is Full HD (1920 × 1080 @30 fps) and undergoes the same processing as any video camera attached to the video call software. The presenter can switch the feed to show either the raw VR headset picture (single eye) or a feed from one of the virtual cameras that they placed in the virtual world (Figure 2). As the virtual cameras provide fixed views of the virtual world, their image quality is less affected by the compression artifacts normally seen on a moving video camera in video call software.



Figure 2. Virtual camera tools inside a virtual elevator shaft. Using the VRCAM menu, the presenter can create a set of virtual cameras (white box) and save or load the set. They can preview and activate the view from each camera using a preview window attached to their VR controller (VRCAM PREVIEW). The first-person view was captured from a stabilized virtual camera attached to the presenter's head (headcam).

To prepare for a training session, the VR guide can pre-position virtual cameras at locations from which they afford the best view of the relevant action. The presenter can quickly preview and switch the camera feeds using the user interface on their hand controller. Further, to simplify switching between cameras, the virtual camera functionality provides for automatic switching between cameras, as well as cameras that automatically follow the presenter. Moreover, as an alternative to the raw VR headset picture that moves with even the slightest head movement of the guide, the presenter can show a feed from a special headcam camera that is designed to maintain a fixed first-person viewpoint until the presenter has moved their head beyond configurable distance and rotation thresholds. The transition between the views can be set to either an adjustable animated pan of the camera or to a straight cut.

3.3. Remote User Study with Experts

This case study was conducted to explore the asymmetric use of VR-based training as a source of contextual information to enrich the remote training session on TAKE 2 double security safety practice, which is followed in elevator installation, maintenance, and modernization. Objectives for the VR training are to learn the preventive measures to secure safety when using hoists for man riding purposes. The study aimed to explore how asymmetric VR set-up should be applied as a part of remote training sessions to positively affect learners' situated learning and knowledge transfer. To address the aim and research question, we conducted a remote user study that replicates the actual remote training session; the focus was to understand how experts perceive the usefulness and value of the asymmetric approach for remote training and to elicit their expert opinion on how to enhance the set-up to advance the learning effects.

The asymmetric set-up granted access to VR training content over two different technologies: via immersive HMD and non-immersive 2D video feed from VR. To facilitate the asymmetric VR-based training session, the users were split into the following roles: (1) a *trainer*, (2) a *VR guide*, (3) a *technical facilitator*, and (4) *learners*—as demonstrated in Figure 3. The asymmetry occurred as follows: the trainer was guiding the training session via Teams, while the VR guide was present in immersive VR, following the instructions, performing safety training tasks, and adjusting the virtual camera to better demonstrate the actions. The technical facilitator was operating a streaming tool to control the virtual

cameras' visibility in Teams and giving some instructions to the VR guide. The learners, who joined via Teams, were able to see the virtual environment and steps of safety training tasks, interact with the senior trainer and leave instant reactions via the "Research Panel" tool (described in the next section). The technical facilitator and VR guide were muted, but they could hear the senior trainer and learners.

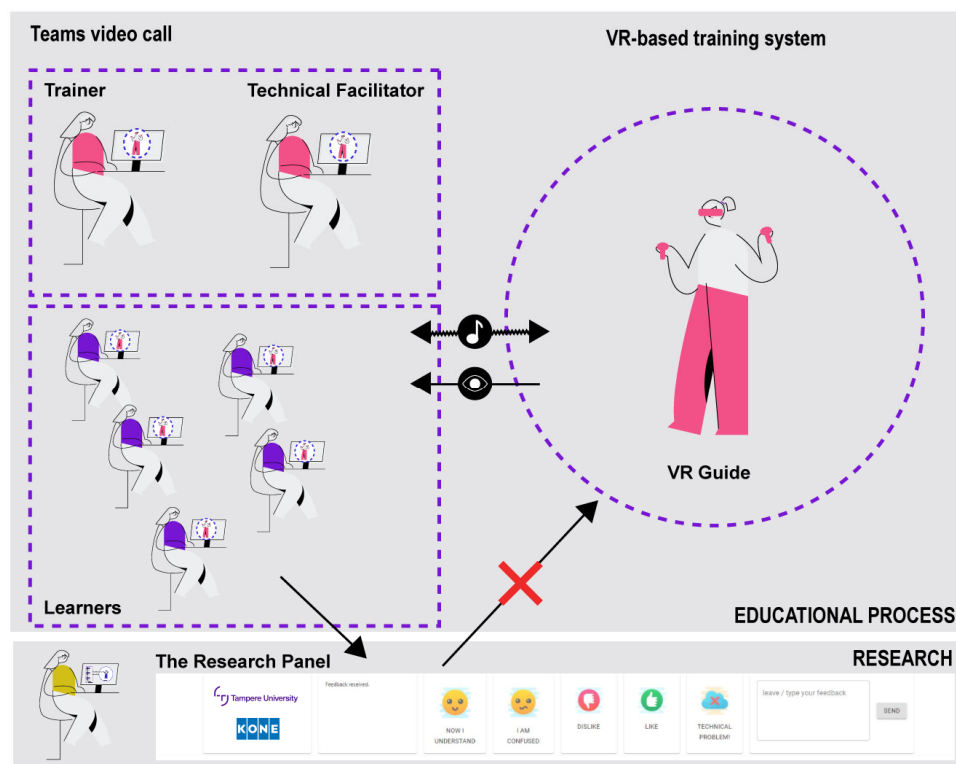


Figure 3. Asymmetric set-up.

3.3.1. Data Collection and Analysis Methods

Mixed research methods were used for the case study, collecting both quantitative and qualitative data. The data, with a focus on a qualitative approach, were collected via pre- and post-surveys. The pre-survey consisted of a consent form collection and a background data collection form, including age, gender, job role, experience, and self-evaluation of maintenance skills. The post-survey consisted of 14 statements (on a 5-point Likert scale, where 1 = Strongly Disagree and 5 = Strongly Agree), open-ended and other questions to evaluate: (1) online training experience in general and occurred technical problems, (2) the content of VR-based lessons, (3) trainer's activities and interactions with learners, and (4) usefulness of VR-based training. The survey quantitative data, due to the relatively small sample size, were used as a supportive data set to observe the main trends—therefore, they were analyzed with a descriptive statistics, showing minimum, maximum, median, and standard deviation values of the responses. Additionally, since ordinal Likert scale was used for data collection, non-parametric one-sample Wilcoxon Signed Rank Test was performed over all the statements individually in parallel. However, it was formality rather than a necessity; we expected no significance due to the small number of participants. Null hypothesis for each statement was based on known median: $H_0 =$ the median of responses is equal to hypothesized median. To counteract the multiple comparisons problem, we have applied Bonferroni correction, resulting in p -value threshold of $0.05/14 = 0.0035$.

In addition, quantitative data were collected in a form of instant reactions via the "Research Panel" tool, shown in Figure 4. The panel was specially designed for the study to gather subjective time-relevant reactions and feedback, which would help to evaluate learners' experiences in certain moments of the learning process. The concept of the "Re-

search Panel” was based on Facebook instant reactions [42], which would be a familiar way of leaving instant feedback throughout the remote training experience. The panel was used by the learners and by the observing researcher; the entries of both panels could be synchronized to gain a better insight into the remote session flow. For learners, the panel consisted of five reaction buttons: one to report a technical problem, a set of negative–positive valence reactions to evaluate learning effects (“I am confused” and “Now I understand”), and a set of negative–positive valence reactions to express overall satisfaction (“Dislike” and “Like”); a text field was available to leave clarifying or general comments.

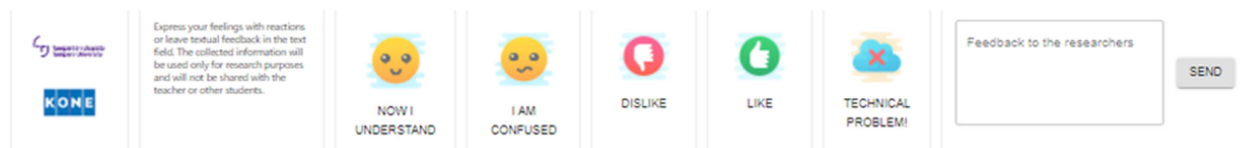


Figure 4. The “Research Panel” tool for learners to collect reactions during the remote training session.

Learners were instructed to actively leave their reactions or comments about the training session whenever they wanted. In addition, the trainer promoted the use of reactions in between different parts of the training module. For the researcher, the panel consisted of four reactions and a text field for comments to track and record the overall flow of the session (“Milestone”, “Problem”, “Important moment” and “User’s reaction”).

The Teams session was video recorded, and the “Research Panel” data were synchronized to the recording using timestamps to allow further combined analysis. We created a novel synchronization mechanism for Teams video recordings by taking advantage of the automatic image thumbnail creation feature in Teams. By checking for the user agent of the Teams image thumbnailing backend, the “Research Panel” page masquerades as an image whenever it is accessed by Teams for thumbnail creation purposes. The timestamp of this HTTP request is logged, and a specific color image is returned, which can be detected on the video recording when Teams shows the link thumbnail. This creates a shared synchronization point on the video and the “Research Panel” server. When regular users click the link and access the “Research Panel” using their browser, the “Research Panel” is displayed normally.

3.3.2. Procedure and Participants

To ensure the success of the procedure and to explore possible issues, the session was piloted twice (a few months and a few days before the session). The first pilot was explorative in nature and included research staff as participants. It was performed with the goal to test the “Research Panel” tool orientation and remote training process with asymmetric VR to generate the exact testing procedure. Based on the pilot, the need for a VR guide and technical facilitator was confirmed, since the trainer found it somewhat difficult to operate VR and provide educational materials at the same time.

The second pilot was performed to practice the exact remote training procedure with two target users—learners—one installer and one trainer. The second pilot study set-up already included a trainer, a VR guide, a technical facilitator in the same location, and remote learners and observers in Teams. Based on the pilot studies, minor improvements were made to the training procedure and user instructions. For instance, it determined the orientation and position of the “Research Panel” in relation to Teams. It also influenced the senior trainer’s different location than the VR guide and technical facilitator, since the trainer became distracted by their communication.

The user study procedure started with introductions and filling in the pre-survey, which consisted of consent and background data collection. The learners were instructed to divide their screen into two areas: the Teams window with a video stream (and other functionalities) taking 80% of the screen, and the “Research Panel” tool to collect instant

reactions taking 20% of the screen (similarly to researcher's screens shown in Figure 5). The link to the "Research Panel" was shared in Teams chat to synchronize all entries.



Figure 5. The screen of the observing researcher.

After participants confirmed that they were ready to start the online lesson, the technical facilitator shared the video from the VR system and the senior trainer started the training process. This is how the senior trainer could focus on teaching and engaging learners while following the VR training, since following the chat discussion at the same time would have been difficult for the senior trainer. Before training, the observing researcher gave technical support on how to divide the screen between the two windows and the use of the "Research Panel". In the training process, the VR guide performed a pre-scripted sequence of tasks and demonstrations in VR, while the trainer narrated the process, explaining and educating on how to perform the maintenance task while giving instructions (to the VR guide) on how to show important details and components over the virtually simulated context. The trainer also initiated discussions with learners, asking them questions and sharing insights. Learners were instructed to use Teams' hand-up function before speaking up and only use the chat for technical help. In between the training modules, learners could ask questions and clarifications.

The procedure was observed by two researchers; one of them also used the "Research Panel" to mark milestones and other procedure-related details; the researcher's screen is shown in Figure 5.

In total, a senior trainer, two facilitators (VR guide and technical facilitator), and nine learners participated in the online lesson. The learner-participants were recruited from the company employees among trainers (8) and installation technicians (1). All of them were male on average 44.8 years old (min = 33, max = 64). On average, they had 12.3 years of experience in current roles (min = 1.5 and max = 44); five of them evaluated their skills in elevator installation and maintenance as "advanced" and four as "expert". Further, five of them have worked frequently in elevator shafts, six have worked with elevator machinery and four worked with KONE's 3D models on a computer screen. As for previous VR experience, two have never used VR, three have taken VR-based training, and four use VR frequently. All the participants, as a part of their work experience at KONE, were familiar with other training solutions of the company and technical documentation—the

main source of maintenance method instructions. Given high expertise in the elevator installation and maintenance operations and training experience from both sides—teaching or participating in the company’s training sessions (e.g., train the trainer approach)—the sample of participants presented a valid and domain-sensitive perspective toward the research question of the study.

4. Results

This section details the results, starting from an overview of the remote training session, followed by the analysis of data collected via the “Research Panel” and summarizing with subjective experiences of experts on the asymmetric VR training approach.

The online learning experience with asymmetric VR training took 81 min and all planned parts of the training module were completed; only the “Research Panel” feedback given during the 81 min of actual training is analyzed. The trainer and learners had several high-quality interactions and discussions during the training module, and the learners showed active participation and a good understanding of the lesson topic. The VR guide successfully completed the task steps and followed the trainer’s guidance to demonstrate the importance of the learning details.

4.1. “Research Panel” Results

A timeline graph of the “Research Panel” results was prepared to illustrate the relative density of positive and negative reactions during different sections of the lesson (Figure 6). Four types of reactions are indicated by colored lines on their respective rows. A fifth “Screenshot” row contains images from the VR view in the Teams video recording; the time of capture is from the middle of each image on the time axis. Light grey vertical bars indicate points marked as “Milestones” by the observing researcher. Milestones are transition points in the lesson which are included on the graph to indicate a possibly heightened propensity to provide feedback since the trainer was instructed to ask for feedback during milestones. Light yellow vertical bars indicate points marked as “Important moments” by the observing researcher. Examples of important moments include particularly interesting discussions or important safety explanations.

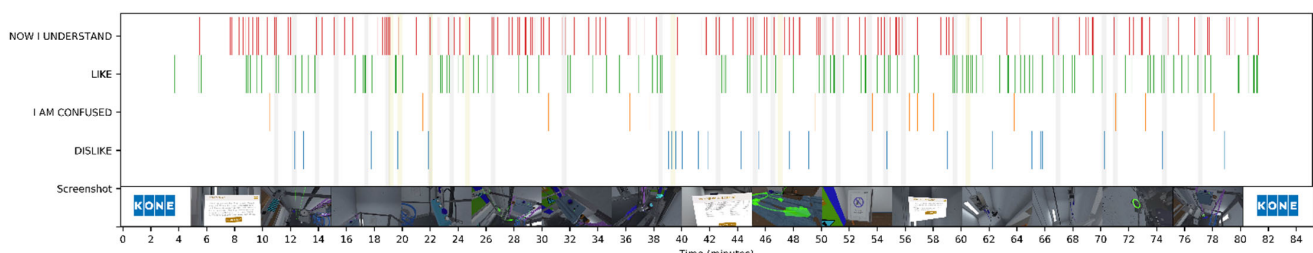


Figure 6. The timeline of reactions collected during the remote training session.

The timeline graph demonstrates a high rate of “Research Panel” usage among the learners and a dominant positive valence of the reactions. The reaction “Technical problem” was used only once by a single participant before actual training had begun, therefore it is not included in the figure. The “Like” reaction was the most used one—it was used by eight participants, with a median of 10.5 times per learner (min = 1 and max = 74). The “Now I understand” reaction was used by seven participants, with a median of 19 times per learner (min = 1, max = 57). The reactions of negative valence—“Dislike” and “I am confused” were used by two and three participants, respectively. The “Dislike” was used a minimum of two and a maximum of 18 times, while “I am confused” was used a minimum of one and a maximum of 14 times. These reactions can demonstrate unclear moments of the training session.

Measuring technical problems during the lesson using an online tool, such as the “Research Panel”, is most likely subject to sampling bias because any technical issues that affect the lesson, for example, network issues or operating system instability, may also

affect the panel. Nevertheless, including a “technical problem” reaction may still be useful for revealing some issues that do not also affect the “Research Panel” itself.

In addition to the predetermined reactions, learners could also provide free-form text feedback during the lesson, shown in Table 1. The participants could attach a reaction to their free-form feedback by clicking the reaction button before or after submitting their text. Free-form feedback was associated with the same learner’s reactions occurring up to 60 s before or 20 s after text submission (in case of multiple reactions, the latest one was chosen). All free-form feedback is categorized in Table 1, sorted by time in ascending order inside each category.

Table 1. Free-form text feedback categorized by associated reaction type.

| Reaction | Learners’ Comments |
|------------------------|---|
| LIKE | P7: “good voice quality” P5: “yes [trainer’s name] we give response:” P5: “clear computer speaker” |
| NOW I UNDERSTAND | P6: “Shat view was good” * P6: “Its clear” P1: “I like the way parts are highlighted” P6: “Parking Mode is very clear” P4: “The text “Great, thanks for your feedback!” does not fade away—because of this it does not really indicate a successful second button press” P6: “GDD ** was clear” P6: “Pendant color coding was clear” P4: “hands are unnecessary” |
| DISLIKE | P5: “skipped the text” P5: “the pop up screen does not start on top of every page” P5: “no time to read the pop up” P5: “not complete explanation” P4: “Hand raising and lowering feels unnecessary” P5: “is only for 1 brand and that is [brand name]” P5: “bad control of the pop up” P5: “skipped the text” |
| I AM CONFUSED | P6: “Forms to updated, GDD ** to be added in the check list” P6: “Take 2 AM *** changed from E to F” P2: “Why can we see better the plate from the pit?” |
| No reaction associated | P3: “tempo is a bit to low for me” P6: “Hook position to be inside” P3: “Almost sleeping” P5: “where is the dust cover” P6: “Please mentions 1.4 m” P6: “Please Zoom the test plate area” P3: “like a short break.: ” |

* Probably referring to the elevator shaft, ** GDD refers to the guiderail derailment detector safety device, *** AM stands for the assembly manual.

As seen in the table, the free-form text feedback was considerably heterogeneous. P3 mentioned that the tempo was too low for them and that they are “Almost sleeping”, whereas P5 said that there was not enough time to read the text in the VR text popups. This could be explained partly by the lesson being too fast in some parts and too slow in others, or it could simply indicate different individual needs and preferences. P4 disliked some unnecessary hand movements. P6 made comments related to both good and bad camera positioning; perhaps a preset reaction could be added to the “Research Panel” for indicating poor camera positioning. P1 gave positive feedback when virtual objects were highlighted; example screenshots of this can be seen at approximately 48 and 72 min on the timeline (Figure 6). Automatic object highlighting in motion is an important benefit of VR lessons, although highlighting could be performed in post-production for traditional training videos as well. There was one comment about the “Research Panel” itself by P4, related to the way the panel indicates a successful submission: the success text changed when sending a different type of reaction from the previous one, but not when sending the

same type of reaction again. This behavior should be changed to better indicate a successful submission in the future.

4.2. Survey Results: Overall Reaction to the Approach

Figure 7 presents descriptive statistics of the survey results (e.g., median, standard deviation, minimum and maximum values) and p-values from the Wilcoxon Signed Rank Test, covering perceived learning outcomes, VR content, trainers' actions, and the overall value of VR and asymmetric VR training. As expected, Wilcoxon Test demonstrated no significance for the statements, especially considering the Bonferroni correction.

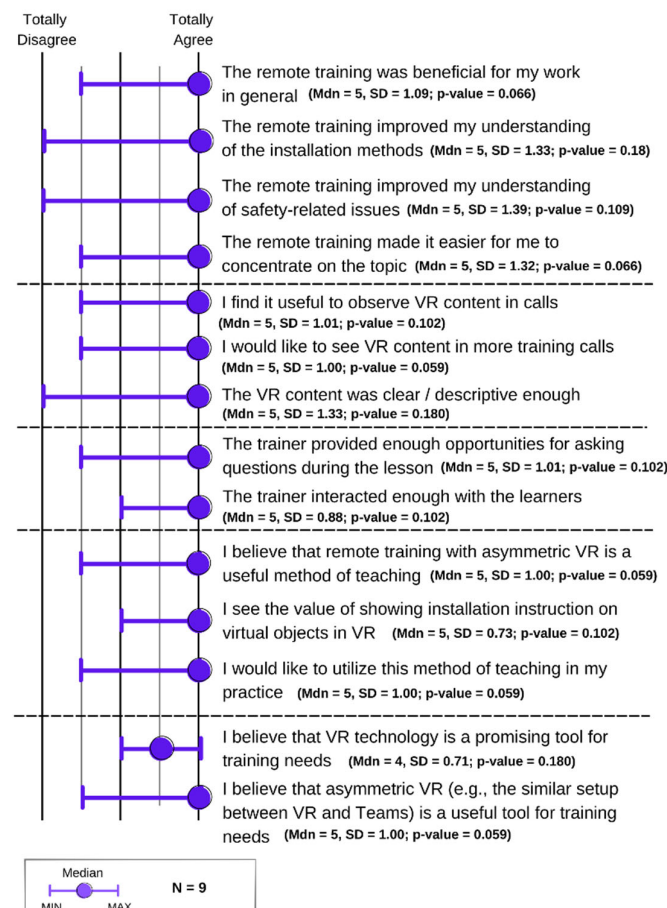


Figure 7. Descriptive statistics of the survey data, presented on a 5-point Likert scale.

However, descriptive statistics and open-ended statements helped to evaluate the overall expert opinion about the topic. As result, the survey demonstrated a positive evaluation of the remote training with asymmetric VR; the participants found VR-based remote learning sessions to be “helpful, clear and easy” (P7) and reviewed it as “an extra tool for sharing information” (P9). Only one participant expressed a negative evaluation of some of the statements, but still mentioned that “It was very easy to understand all issues off training” (P6).

Nevertheless, the majority still evaluated the approach of using asymmetric VR for remote training sessions extremely positively; most participants agreed or strongly agreed that remote training lesson improved their understanding of the method (8/9), improved their understanding of safety-related issues (7/9), and was beneficial for their work in general (7/9). Further, more than half (6/9) agreed and two disagreed that remote lessons made it easier to concentrate on the topic. Staying concentrated while attending remote lessons was found to be an issue by several participants; one of them mentioned that it was “difficult to remain concentrated for a long time. Face to face is always better when we are

talking about safety for installation" (P5). Moreover, two participants expressed their concern about the remote nature of the lesson commenting that *"you can't check if the trainee is really watching"* (P9) and *"there is always a possibility that learners start to do something else"* (P1). On the opposite, one participant mentioned that VR content is less boring than the slides with technical documentation and pictures, which would be traditionally used for remote training sessions.

As for the matter of using VR content in remote training lessons, eight participants agreed or strongly agreed that it is useful and clear/descriptive enough. Further, eight participants would like to see more VR content in future remote training, commenting that *"I will use the VR in my remote training"* (P3), *"use the asymmetric VR before a face-to-face training on-site"* (P5), and *"we can even show it how to make installation of lift"* (P6). When evaluating the view of the VR content (VR user point-of-view vs. static camera), eight participants marked that both methods worked well, and one favored the VR guide's point-of-view.

The trainer's activity was also observed as positive: eight agreed that the trainer provided enough opportunities for asking questions and seven agreed and two were neutral that the trainer interacted enough with the learners. Three participants found the hand-raising activity to be unnecessary and suggested allowing free voice interaction between trainer and learners without this formality. The speed of the trainer's actions was found to be suitable by eight participants; only one pointed out that it was too slow. From other suggestions, participants mentioned that pop-ups with information (training embedded) should stay longer on the screen and that trainers' speech *"could be added to the automatic instruction as well"* (P4).

Finally, the participants left the following supportive comments, shown in Table 2, to express the benefits and application case for the asymmetric VR approach.

Table 2. Quotes from experts.

| # | Participants' Comments |
|----|---|
| P1 | <i>"Nice way to update Take 2. This will save a lot of traveling costs" "I think online VR training can be used for recertification. Also, the theory in the F2F course can be replaced by a VR (not remotely)."</i> |
| P2 | <i>"I think VR is a good type of training if going to a site isn't possible" "Flexible training solution not dependent on participants location—almost real site experience."</i> |
| P4 | <i>"It was easier to maintain interest in the topic, just looking at pictures would be boring"</i> |
| P5 | <i>"Not bad in fact for a first theoretical approach"</i> |
| P6 | <i>"I think we should have both VR training and practical final exam * for students live"</i> |
| P8 | <i>"Very informative and good to have a refresh, train the trainer **, session to brush-up our knowledge and previous training and to add more information when we are delivering our sessions to FL ***? "to be as an app can be installed on the trainer system without the VR system and can be used directly by the trainer to demonstrate to FL because not all time we can access the VR lab every time we need to deliver a session"</i> |
| P9 | <i>"It is good to do a session like this before people come to the training center, so they have a better understanding before the real training starts"</i> |

* final exam is usually a practical assessment, where Learner needs to demonstrate they're able to follow the method when doing installation tasks. This needs to be renewed every five years. ** train the trainer refers to the system KONE uses in technical training. Global trainers train area trainers, who then again train local trainers. *** FL stands for frontline, which means country organization.

4.3. Comparison of Asymmetric VR Training to Other Training Solutions

Figure 8 demonstrates the comparison of the training session with asymmetric VR to other available methods at KONE (other training solutions, technical documentation, and real-life training). All the participants, due to their work experience, were familiar with the listed methods—attended face-to-face training on the topic and also read the technical documentation. The question was created to understand if the company's experts see any additional value in observing VR content over a 2D screen, and positive responses would

be given via clicking on a checkbox, while the checkbox option “none of the above” would be used to show a negative response—e.g., no value over existing solution.

I think, that observing VR content was better than the following, because:

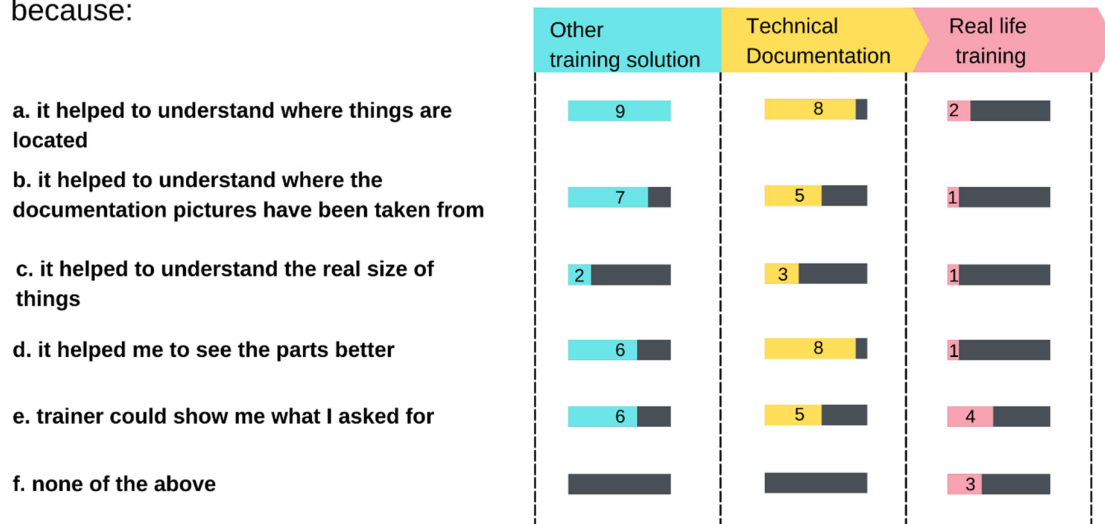


Figure 8. Comparison of asymmetric VR-based training to other available solutions. The numbers in the figure show how many experts agreed with the mentioned statement.

The figure indicates that asymmetric VR training holds several advantages over the existing methods. Primarily, none of the participants marked “none of the above” when marking the benefits over other training solutions and technical documentation. The major advantage of using the content from VR was finding the possibility to understand where the maintenance objects are, where the pictures in technical documentation were taken and to see the parts better. Interestingly, the possibility to ask questions and learn the answers in the context was marked as beneficial in comparison to not only other training solutions and technical documentation, but in comparison to real-life training as well. Finally, based on the result, asymmetric VR training lacks the understanding of sizes, since for only a few participants it helped to understand the real size of things.

5. Discussion

In this article, we presented the concept of enhancing remote training experiences using asymmetric VR as one source of visual and contextual information. To investigate the usefulness of the approach, we conducted a remote user study with ten training and installation maintenance experts from an elevator manufacturing and maintenance corporation (nine acted as learners). During the study, we collected instant reactions via the “Research Panel” tool, which helped to gain deeper insight into the session flow and spot problematic parts of the training module.

Conducting user studies in an industrial context with actual representatives often limits the number of participants and, thus, may raise concerns about the validity of produced results. On the other hand, it provides context-relevant and accurate insights from selected domain experts with extensive industrial experience in response to the actual industrial challenge. The elicited data may further be generalizable for other industrial training processes with similar challenges (e.g., limited or no access to industrial context and components), but also may guide towards smart re-utilization of industrial VR technologies and, as result, wider adoption of it in the asymmetric set-ups.

5.1. The Benefits of Asymmetric VR for Industrial Training

Our findings demonstrate the high relevance of asymmetric VR-based training to enrich the remote learning experiences of elevator company employees and provide educational materials in a realistic context, inaccessible otherwise. The use of asymmetric VR for remote training was evaluated extremely positively by industrial experts and was seen as “an extra tool for sharing information” (P9). Such asymmetric set-ups can be utilized to address many of the training scenarios: (1) updating and refreshing maintenance or installation methods together with safety principles among trainers (“train the trainer” approach), (2) certification of employees or exam-taking globally, (3) the first theoretical introduction of the topic, or (4) introduction before visiting a training center or on-site locations.

Based on the subjective comparison, the use of VR content is a clearer educational resource than existing training solutions or technical documentation. The results suggest that even without being immersed in VR, observing someone else’s actions may improve physical proximity understanding and comprehension of maintenance components. A big advantage of using asymmetric VR during remote training was seen in the ability of the trainer to interact with learners, explain materials and answer their questions by showing context-sensitive details in the VR environment. This indicates a clear advantage of using asymmetric VR rather than video recordings of the same procedure.

The only limiting factor was a lack of real size understanding when viewing a representation of the virtual environment on a 2D screen. On the other hand, lack of real-size understanding is a common problem, which can be achieved only with immersive training in VR or hands-on training in the real context with real components. Another interesting finding of the study suggests that a video feed from VR, controlled by the trainer or VR guide, is a better alternative than a desktop user interfaces for the VR system. During the training session, the trainer should have full control of what learners are seeing, which would not be possible if the learners can freely move in VR.

The “Research Panel” results in Section 4.1 demonstrate an overall positive reception of asymmetric VR by our small sample of nine learners. The majority of learners did not give any negative reactions and the number of positive reactions far outweighs negative reactions. Nevertheless, some issues were identified with camera positioning, pacing, and text display. Ideally, all text should be displayed without skew in a separate window for asymmetric learners instead of through the virtual camera of the VR system. During our lesson, some text was displayed in a separate window while some was displayed through the virtual camera: the experience could be improved by giving learners individual interactive control over certain non-VR aspects of the system, such as text popups. Overall, the “Research Panel” gave many useful context-specific insights that can and should be used to improve lesson content in the future. The data show that negative reactions seem to be limited to specific rare moments rather than being a general feature of learners’ experiences. Therefore, based on the data from the “Research Panel”, for example, it would be possible to determine which parts of the training module were clear and increased the situated learning and, on the contrary, which parts of the module caused confusion. This, in turn, would allow the trainer to make modifications for the remote training session and ensure better educational effects.

In conclusion, our study indicates that the existing VR training systems can and should be utilized asymmetrically as a part of the remote training process, which would deliver certain benefits for situated learning and enhance the effects of knowledge transfer. Based on the study insights, we have summarized a list of suggestions to complement the adoption of asymmetric VR for training purposes, detailed in the next section.

5.2. How to Apply VR Asymmetry for Remote Training

Answering the research question of the study (How should asymmetric VR be applied to facilitate remote training sessions and improve knowledge transfer?), we suggest the following considerations:

1. **Assign and test the role division.** Our case demonstrated the need for several roles when using a VR training system as a part of a remote training session. The piloting sessions showed a high mental load for the trainer to be present in a virtual environment, provide educational materials, and interact with learners at the same time. Therefore, supporting the finding from the previous work [27], we propose to distinguish the role of a *VR guide*. This role should be filled by a person who is knowledgeable in the topic of the training session and experienced with a VR system in use. In constant with Horst et al. [27], who suggested that a VR guide should be using a VR system over a 2D screen, in the case of training, a VR guide should be present in a virtual space, follow the instructions from the trainer, and guide the learners' attention. Next, our study presented another role—*technical facilitator*, who assisted with the integration of the VR feed into Teams. We also suggest that with a certain level of training, the trainer could take this responsibility once the use of VR is permanently integrated into the remote sessions and the process of building an asymmetric setup is clarified.
2. **Define processes and best practices into the set of instructions.** Any novel integration of technologies should be supported with a set of guidelines. Trainers, despite being extremely skilled in the field of their work, might not be frequent users of technology. Therefore, to enable smooth integration of asymmetric VR usage and avoid resistance towards its adoption, we suggest the need for clear instructions for both teaching interaction procedures (similarly to [43]) and for technical support. It would decrease stress related to using the technology, and associated costs, e.g., the role of technical facilitator could be added to the trainer's role. On the other hand, we noticed zero resistance towards adopting asymmetric VR for training purposes. On the contrary, subject matter experts expressed the desire to start utilizing it, while clear instruction would support their desire and help to start using it.
3. **Use VR to show only context-sensitive details.** While the use of VR content was useful for showing the context and the components, which would be hard to demonstrate in reality, the textual components in VR were not easy to read and comprehend. The participants' comments, collected via the "Research Panel" tool, demonstrated that reading the information in pop-ups was difficult and they had not enough time to complete it. Therefore, to increase the effects of meaningful learning, similar to Mystakidis et al. [28], we suggest combining the use of VR learning with traditional instructional strategies—meaning planning and integrating a hybrid flow of the VR training, so the information, such as textual instructions or checklists, should be still delivered over a traditional 2D screen.
4. **Allow and plan multiple ways of showing the content in VR.** The main benefit of utilizing a VR as a part of the remote training session is the ability to visualize and demonstrate context and equipment. Despite the majority of the participants finding that both methods (point-of-view and static camera) worked well, it was also noticed that zooming in on the objects would sometimes be useful. Hence, special attention should be paid to the way that virtual cameras are arranged in virtual space to enhance the viewing experience of learners. For a maintenance or installation procedure, for example, it would be good to have several shot types, similar to a professional training video production [35]—close-ups to demonstrate the details, medium or over-the-shoulder shots to visualize hand movement and tools when performing operations, and a full shot to show the procedure in its context. Further, a simple interaction to switch between the modes would greatly affect performance and advance the visual capabilities of VR in remote training.
5. **Allow more interactivity for learners.** In our study, we asked the learners to stay muted for the duration of the training session and use the "hand-raising" function to obtain permission to ask questions, always. This was implemented with the purpose of minimizing distractions for the trainer. Nevertheless, the learners found this approach unnecessary and expressed the desire to actively participate in discussions

without the trainer's special permission. This is especially relevant for the moments in between the module's parts when the learners have a specially assigned time for questions. Therefore, we suggest dividing remote training sessions based on the asymmetric use of VR into a *silent mode* (when learners should be listening to the explanations of a trainer and should raise a hand if they wish to ask questions) and an *active mode* (when learners can freely participate in the discussion and ask questions). Additionally, the data from the "Research Panel" indicate system developers should also consider adding interactivity for certain non-VR elements, such as text popups, so that learners can read them at their own pace.

6. **Collect data during the training sessions.** The data gathered with the "Research Panel" were highly useful to evaluate the flow of the session in general and highlight the parts which would require additional attention and modifications. Learners will not necessarily remember specific details afterward during a post-lesson questionnaire, and timestamped data provide important context for their feedback.

To summarize, with this article, we demonstrate an industrial case study on how to re-utilize existing industrial VR systems with the goal to enhance the quality of maintenance and assembly training sessions, forced to become remote during the pandemic. In contrast to the earliest study on distributed asymmetric training in a similar context [33] and the resulting system, which uses real-time stereoscopic rendering of 3D models to facilitate interactive training in an immersive learning classroom environment, we propose a cost-efficient and scalable way of training based on VR content, accessible from trainees' home environments. For KONE, the adoption of VR provides additional value, such as giving the possibility of visiting an elevator shaft to non-field workers, enabling them to gain a better perception of the products and environments that the company is working with. The asymmetry, in this case, is a useful approach in the post-pandemic world as well, since it would increase the scalability of VR systems by allowing wider circles of employees to obtain access to simulated environments easily and sustainably—without the need to travel to the physical location or VR-equipped training center. Further, collaborative virtual environments may enhance department-to-department collaboration in product development [44–46], maintenance methods, and technical documentation creation [5,16,47], at the same time improving the innovation capability of remote distributed teams [48]. Digital content created in VR can be further used for several purposes, such as internal communication or showcasing to customers. Therefore, the value of VR adoption in the industry lies far beyond the classical understanding and direct benefits of the applied use cases, which indicates that the re-utilization of virtual environments and digital content, created in VR, should be further explored.

5.3. Limitations and Future Work

This study has several limitations. First, it was based on a single company case within a specific domain. The participants of the study were company employees (trainers and installation technicians) with advanced or expert skills in elevator maintenance and installation, which results in both advantages and drawbacks. On one hand, the expert perspective and domain knowledge is critical when testing future technological adoptions which they will possibly be using. On the other hand, the effects on situated learning and knowledge transfer might be lower for novice maintenance trainees due to a lack of existing experience and knowledge. Therefore, future work should include more investigation with novice learners to make a complete statement on the usefulness of asymmetric VR for remote training.

Co-located use of asymmetric VR during face-to-face training could also be explored further, similar to [33]. A hybrid system incorporating multiple connected devices with traditional displays and HMDs could improve the viewing experience for the content which is not adequately displayed by mirroring the HMD view; this solution especially makes sense for groups when there is not enough time for everyone to try the VR system individually and is more cost-effective than simply scaling the number of HMDs. When

experimenting with hybrid and distributed systems for training purposes, attention should be paid to the evaluation of the transfer and learning effects, similar to [36].

In our study, the “Research Panel” data could easily be analyzed manually. Future work could explore automated methods and different visualizations, for example, video overlays or subtitles, which may be required for larger amounts of data. Subjective feedback on lessons may have a positive bias due to social factors; future work could concentrate on ways to detect and correct a possible bias by including new types of indicators. These should be synchronized with other session recordings as was conducted in our research panel implementation.

6. Conclusions

This study provides concrete experiences, tools, and guidelines to advance remote training sessions in the context of industrial maintenance, installation, and occupational safety. With this study, we demonstrate how the utilization of asymmetric VR (as a source of visual and contextual information) makes it possible to increase the quality of remote training sessions and positively affect situated learning and knowledge transfer.

The presented industrial case study was performed as a collaboration between academia and industry to investigate the potential of re-utilizing existing VR systems to adjust to the changes in the fast-developing world, for instance, forced social isolation and related challenges. In this research, we evaluated the means of supplementing remote training sessions with the asymmetric use of the VR training system. Based on domain experts’ insight, we formulated design guidelines to support the adoption of distributed asymmetric VR. The guidelines are generalizable to other industrial contexts and provide factors to consider and practical suggestions when supplementing industrial processes with asymmetric VR. Among other insights, we discuss the importance of defining roles (differentiating VR guide role), and procedures to ensure the best possible flow of the training session. We also suggest not basing such training sessions purely on VR content but considering using traditional methods when applicable. In addition, we present the concept of the “Research Panel” tool to gather instant reactions during such training processes. It could help to identify problematic or unclear parts of a training module with a final goal to enhance the process for the future.

As the pandemic forced many industrial operations (e.g., face-to-face training or collaboration) to become remote it is essential to adapt and find ways to enhance current work practices. Our findings demonstrate that asymmetric set-ups can be applied over existing VR platforms to grant access to VR content. In this way, they can support many industrial operations and scenarios. The benefits of asymmetric VR go beyond the pandemic since it increases the scalability of industrial VR and has many potential use cases to positively affect the sustainability and resource efficiency of industrial processes.

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