Toward Efficient Academia-Industry Collaboration: A Case Study of Joint VR System Development

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ABSTRACT

Collaborative academia-industry development and evaluation of virtual reality (VR) systems is a mutually beneficial opportunity to investigate VR technology in a real context and conduct user studies with target users. However, such collaboration is rarely performed due to variations in project pace and work methods. In this article, we introduce the process of action research on joint design, development, and evaluation of a collaborative VR system to address industrial needs. The paper further presents employees' subjective opinions and perceived value of industrial VR applications and reflects on their involvement throughout the process. The article concludes with a process-oriented framework for remote academia-industry collaboration, supported with practical suggestions on how to support this collaboration. Our experiences reveal the methods and advantages of remote collaboration in all phases of the process and signify the efficiency of the remote framework for academia-industry collaboration, especially relevant in the light of the COVID-19 pandemic.

CCS CONCEPTS

• Software and its engineering ~ Software creation and management ~ Collaboration in software development

• Human-centered computing ~ Human-computer interaction (HCI) ~ HCI design and evaluation methods ~ User studies

KEYWORDS

Academia-Industry Collaboration, Industry-Academia Collaboration, Virtual Reality, Collaborative Virtual Environment, Industrial Maintenance

*Article Title Footnote needs to be captured as Title Note
†Author Footnote to be captured as Author Note

ACM Reference format:

FirstName Surname, FirstName Surname and FirstName Surname. 2018. Insert Your Title Here: Insert Subtitle Here. In *Proceedings of ACM Woodstock conference (WOODSTOCK'18). ACM, New York, NY, USA, 2 pages.* https://doi.org/10.1145/1234567890

1 Introduction

With the growing capabilities and availability of virtual reality (VR) technologies, both academia and the manufacturing industry are investigating their potential and applications. The industries are striving to take a leading role in adopting the technologies into everyday use due to the potential of enhancing their working processes and overall efficiency while decreasing costs [23]. One of the major industrial use cases is using VR for remote collaboration and communication when performing design, development, and service-related activities in the field of manufacturing and construction [18, 23]. Industrial teams located across different countries require flexible tools for remote collaboration with rich ways of information representation and sharing.

In this case study, VR is approached from the perspective of the documentation creation process, based on iterative collaboration with multiple departments. Traditionally, for maintenance methods and documentation creation, the interpretation of the products' 3D model has been conveyed via 2D screens, which may cause misunderstandings, such as scaling or spatial errors in the creation process (e.g., if certain parts in the product are not reachable). Such errors can cause product or documentation design flaws: For example, a situation where a maintenance technician's hand or tool does not fit where it should when performing the task. VR, apart from introducing enhanced remote collaboration opportunities [5 ,8], can be also applied to enrich visualization capabilities and simulate interactions with real objects to overcome the challenges mentioned above [1, 14, 30]. In addition, previous work has demonstrated a need and desire to utilize innovative technologies to increase employees' motivation and overall company's performance [7, 19]. The topic of remote collaboration in VR became especially important in the light of the COVID-19 pandemic when in-person meetings have been restricted for safety reasons even for teams from one location, causing barriers for efficient communication.

To successfully and meaningfully implement VR technologies to support the industrial working processes in a cost-efficient manner, extensive research should be performed to identify users' needs and contexts, system requirements and iteratively verify corresponding design solutions. Hence, industries can greatly benefit from collaboration with academia, whose knowledge expertise and research methods would ensure the validity and relevance of resulting designed solutions. Thus, the involvement of academia, despite possibly a slower work pace and more abstract goals [6], may decrease the overall duration and costs of a software development project [17].

The traditional model, where academia deploys prototypes and generates the knowledge as an outcome of user studies with these prototypes, and industry utilizes these afterwards, does not work efficiently in the vastly developing and changing world. Furthermore, traditional academic research, which is more focused on studying separate aspects, such as ergonomics and interactions, may not fulfil the industrial needs, and as a result, deliver irrelevant and ungeneralizable results due to a lack of access to target user groups and contexts. Academia, in turn, benefits from collaboration with industry by being exposed to real industrial needs and target users. [29] Hence, the collaboration between academia and industry is of undeniable value to both parties. Nevertheless, such collaboration often faces multiple challenges due to differences in working methods, goals, and time horizons [11, 24] and is, therefore, rarely performed [2]. To overcome these challenges and drive innovation development, there is a need for clear processes and methods to accommodate smooth and efficient collaboration between academia and industry.

This article presents the work done within the HUMOR project. The project provided an opportunity for academia and industry to work together and solve common issues, which resulted in open and efficient knowledge sharing and transfer. The two collaborating partners were a group of human-technology interaction researchers from academia and a group of research & development professionals from the manufacturing industry and industrial maintenance company. Based on the challenges of academia-industry collaboration mentioned above, our motivation for this article is to share our practices and demonstrate the benefits of such collaboration. Hence, we aim to answer the following research questions:

RQ1: *What are suitable methods and processes to enhance remote academia-industry collaboration?*

RQ2: *What are the benefits of a joint academia-industry development process in the case of a VR system?*

To address the research questions, we defined two research objectives. Firstly, we aimed to apply user-centered design and agile methods [10] to the design and development of the VR system and base the collaborative activities on involving relevant stakeholders to the decision-making process. Next, we planned to include expert employees from the industry to the development and evaluation process and measure their perception of the system design and its effectiveness for the company's needs in an iterative manner.

In summary, this article demonstrates a collaboration between an academic and an industrial partner (KONE) to design, implement, and evaluate a collaborative virtual environment (CVE). The resulting system, called *COVE-VR,* was created to enable efficient department-to-department collaboration in the pipeline of service-related work – even between teams and people located in different places. Due to the COVID-19 pandemic, the development collaboration was shifted to happen remotely, which caused changes to the planned activities and the adoption of remote practices and methods. The performed work indicates the potential of executing remote collaboration processes: They can unite academics and industrial practitioners from around the globe to work jointly on a common task with mutual benefits for both sides.

The main contribution of this article is *a framework of remote academia-industry collaboration,* shown in Figure 1. It can be generalized to other use cases to build trust, shared understanding of research goals, and established time horizons, thus addressing the major barriers of academia-industry collaboration. The framework is further supported by a list of practical suggestions to ensure that the collaboration process is efficient and beneficial for both parties. Our evaluation results show that the company's employees think very positively about integrating VR technologies into their working tasks and see value in it. These findings support the efficiency of the suggested framework: Through the joint efforts academia and industry accomplished their shared goal and delivered the software that caters to the needs of the target user group.

2 Related Work

This section presents two major topics of the article starting from the aspects of academia-industry collaboration and followed by a background to collaborative virtual environments (CVE), reflected from the industrial perspective.

2.1 Academia-Industry Collaboration

Academia-industry collaboration holds the potential to drive innovation and wealth creation [2, 4], especially in the fields of Human-Computer Interaction (HCI) and Software Engineering (SE). The knowledge and experience sharing between academia and industry addresses the lack of relevance in research by merging the actual industrial needs with research goals and scientific knowledge while utilizing verified academic methods to extract data from industry experts and target users [6, 12, 22]. Additional benefits of such collaboration are increased funding efficiency, the stability of processes, privilege growth, access to varied expertise, state-of-art equipment and facilities [2].

Nevertheless, academia-industry collaboration is not a simple process due to differences in objectives, perspectives, working methods, operating modes, and time horizons [11, 22, 24]. For instance, academics may fully concentrate on projects and work on more theoretical and abstract levels to achieve long-term research goals, whereas industry has its rapid deadlines, short-term priorities and practicalities overriding academic interests [11]. This may result in a lack of understanding, unrealistic expectations, and even mistrust between parties. Other challenges include a lack of relevancy, experience, and skills to support a collaboration process, minimal commitment and interest, inflexibility, and managemental and organizational issues [11]. The barriers may be further categorized as orientation-related (differences in orientation and stimulus) and transaction-related barriers (conflicts over administrative procedures and knowledge property), of which the latter are harder to mitigate [6].

To address these barriers and connect academics and industries worldwide closer together, there is a *need for a generalizable process-oriented framework of remote collaboration*. Various models and guidelines, summarized in the literature review by Garousi et al. [11], have been proposed to enhance collaboration and support information and experience sharing, for instance, based on agile [22] and action research [21] practices. The latest proposed model, called Certus, based on eight years of longitudinal qualitative research, highlights the importance of seven elements of the collaboration to support knowledge co-creation: problem scoping, knowledge conception, knowledge and technology development, transfer, exploitation, organizational adoption and market research [15]. However, to the author's knowledge, none of the existing models provides a clear understanding of processes to establish *remote collaboration and knowledge sharing* between academia and industry. To fill this gap, based on the best practices of user-centered design and agile methods [9, 20], this work presents the process-oriented framework to support the academia-industry collaboration on VR system development.

2.2 Industrial VR and CVEs

Due to increased adaptability and flexibility, VR offers an endless spectrum of possibilities when it comes to addressing industrial needs [7, 9, 23, 27, 30]. Industry aims for more efficient processes in product design and work method development, as well as overall shorter times to market including training the personnel about the product. One of the solutions to save time and resources, while optimizing the development and management processes, is to enable efficient remote collaboration in VR [18, 23]. Benefits are likely since remote development work via traditional conferencing tools can leave plenty of room for interpretation and cause misunderstandings. Virtual worlds, in turn, have proved to be a suitable collaborative environment for designers to support conceptual design activities due to enhanced communication, awareness, and the availability of virtual tools [15, 26].

Collaborative virtual environments (CVE), defined as virtual worlds shared over a network [16], provide solutions to several challenges in global collaboration in industrial settings [5, 8, 15]. CVEs may support synchronous and asynchronous remote collaboration while enabling flexibility in the visualization of shared data [8]. They may further enhance remote collaboration, experience and knowledge sharing [20] via increased immersion and realistic multisensory object manipulation with collision detection [1, 14]. Besides, due to a positive perception of VR technologies, collaboration within VE may advance employees' motivation as well as the overall company performance [7, 19]. In concrete terms, CVEs can enhance the communication in the development process by providing access to 3D models, e.g., in virtual reality to all the relevant people and having them see what other parties are referring to. An example from the manufacturing field [30] presented a multimodal VR tool for design reviews and demonstrated that such a system can facilitate communication between assembly operators and engineers. In addition, such a VR system further enables validation of installation processes and simulation of testing and maintenance tasks.

Product development in CVEs can also enable the involvement of other departments in an earlier phase of the process, thus contributing positively to the time to market [23]. Creating a tool for enhancing the development process and including all relevant teams to collaborate has long been among the goals of the industry. Virtual reality caters partly for all these needs. Despite all the benefits, the implementation of VR technologies to the industry is still limited due to lack of time and specific knowledge or VR experts in addition to methodological flaws, such as discrepancies between industrial needs and the final solution and a rare utilization of target users (company employees) [27]. Hence, to reach the best possible outcomes in VR development, industry and academia should unite their forces and work in tight and open collaboration, whereas user-centered design and agile methods may be applied to coordinate the collaboration [10, 11, 22].

3 Academia-Industry Collaboration Process

The development process was structured by adopting *a user-centered design model* to the industrial context and involving various focus groups. One academic and three industrial groups, defined in Figure 1, participated in the whole processes.

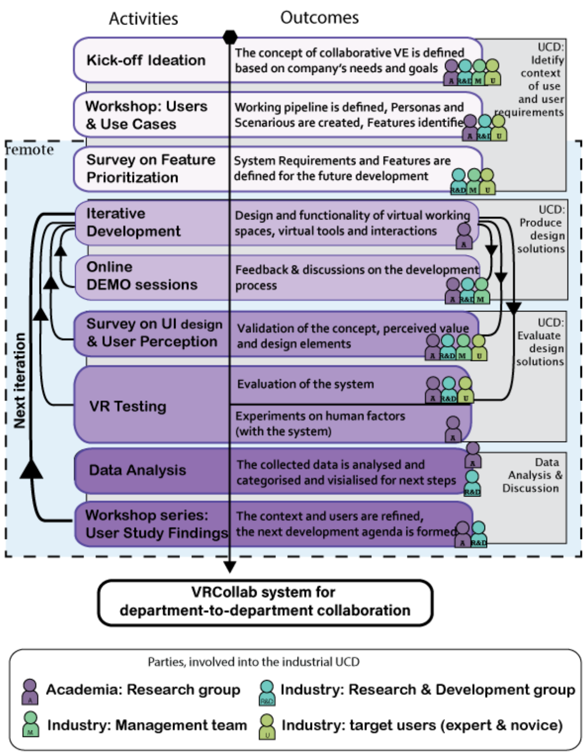

Figure 1. The framework of remote academia-industry collaboration.

The *academia* was represented by a team of multidisciplinary researchers, including VR developers, user experience and visual designers. The *industrial partners* (the manufacturing company with a strong focus on the maintenance of the equipment) participated in the process in three groups: 1) *industrial research and development team* (R&D), 2) *managers and team leads*, represented by industrial seniors, influencing the decision-making process, and 3) *the future users*, represented by the multinational company's novice and expert employees. The collaboration process was performed between the academic research group and the industrial research group on equal terms, whereas the management team and target users were involved as focus groups. The industrial R&D team's participation assures that industrial aims are tightened to the research process and grants access to the other groups. The management team's presence guarantees that the performed research and development process corresponds to the business-oriented goals of the company, whereas the involvement of the company's employees grants the access to specific, end-user knowledge and insights, which are important for the overall success. The process consisted of the following activities, presented in Figure 1 and detailed below.

1. Kick-off Ideation meeting was initiated with a goal to create a shared understanding of the industrial needs and core values of future collaboration. The kick-off meeting was held with the academic team, industrial researchers, management team, and representatives of the target user group. Started with presentations from industrial managers, the meeting evolved into an ideation workshop, where three major areas of interest related to VR were discussed (i.e., technical documentation aspects, department-to-department collaboration, and data collection and analysis). The ideation process happened in three dynamically arranged teams, which were, in turn, ideating and linking the aspects of three areas of interest into one topic. As a result, the attendees developed the concept of a virtual environment to enable department-to-department collaboration for employees involved in the technical documentation creation process.

2. Maintenance Documentation Journey Workshop was arranged to get a clear picture of the end-users and their work tasks. The creation of maintenance documentation involves two departments: subject matter experts (expertise on maintenance methods and equipment) and documentation experts (expertise on information design, technical writing and illustrating, and documentation tools), who co-create instructions and iterate them until a final version is approved, finalized, and published [13]. Academics, industrial R&D, and target users were involved in the workshop and discussion. A maintenance documentation journey (Figure 2) was presented to the participants to elicit their comments and important details about the process. The participants were then divided into three groups to discuss the challenges of the journey, the opportunities that the VR scenarios could offer, and the user requirements for the CVE system design.

The workshop took place in Finland at company premises. Two participants from India participated remotely; their participation was facilitated by a Teams video meeting on a laptop. A separate USB camera was used with the laptop, which enabled the remote participants to turn the camera to the current speaker or materials. A separate speaker microphone was used to ensure good audio quality.

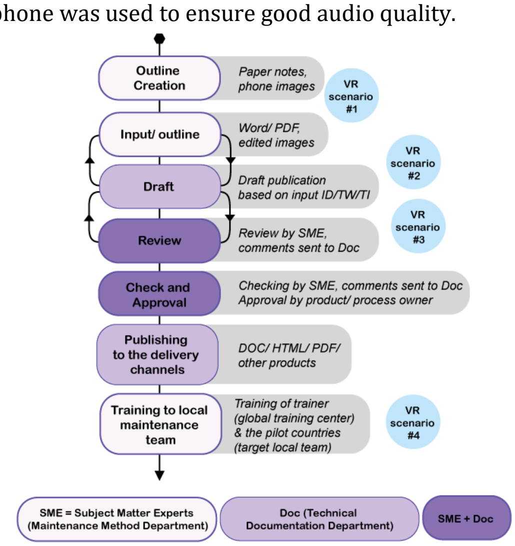

Figure 2. Maintenance documentation journey

The Indian participants felt they were well involved in the workshop and commented that the remote participation worked very well. The workshop resulted in the creation of the pipeline of working activities and corresponding users' needs for the system to support those activities. Personas, drafted prior to the workshop, were finalized for each department representative as well as scenarios of how the work can be done within the virtual environment. Further, system functionality and required features were identified.

3. Survey on feature prioritization was designed to collect the perceived value of system features from the future end-users. The results from the workshops (i.e., all comments regarding Maintenance documentation journey, VR use cases, ways of working) were digitized, and all features of "an ideal collaborative VR environment" were listed. Features were divided into six categories: *Tools, Notes, (VR) Environment, Integration, Timeline,* and *Other*. People were invited to a guided Teams session to fill in the feature prioritization survey to ensure that everyone similarly understands the features and people have reserved time to answer the survey.

Firstly, the features were explained, and participants were able to ask questions if they had any doubts. Then, the participants opened the survey from their computers privately and filled it in. The Teams session was kept open until all participants had confirmed that they had finished the survey. In the survey, the features were evaluated on a Likert scale through the question *How important you consider the following features in VR?* Since all features had already been identified as important earlier, the scale started from "somewhat important" instead of "not at all important" (1 = somewhat important, 5 = extremely important). Webropol tool was used to conduct the survey.

4. Iterative development process & Feedback via Demo Sessions was established as a process for academia to finalize the design and develop the system while getting constant input and reflection from industrial partners. The academic research team performed the process of designing the user experience and interactions with the system based on the previous phases of collaboration. The major goal was to find the balance between implementation feasibility and the level of complexity of interactions and user interface design. Once the system development progressed, video meetings with the industrial representatives were arranged to demonstrate how the system's functionality was implemented. After video demonstrations, both parties discussed possible modifications and future development agenda and associated deadlines.

5. Survey on the system design was created to rapidly gather feedback on the system functionality from managers and target users in the company. When the first version of the system was deployed, the VR user studies were delayed due to the COVID-19 pandemic situation. Hence, we decided to collect both quantitative and qualitative data in a form of an online survey. It consisted of multiple parts, collecting subjective opinions on the perceived value of the system, virtual spaces, and virtual tools. The survey was designed by the academic research group and iterated based on the feedback from the industrial research group. The responses of the survey verified that the system design is sufficient and useful from the perspective of the company's employees and management team and resulted in minor system modifications (e.g., the order of items in the menu). A more concrete description of the survey structure and respondents is presented in section 5.1.

6. User study with expert users was planned in meetings and asynchronous cooperative work between the academic team, industry researchers, and industrial experts. In the initial planning meeting, academics and industry representatives agreed on the features to test and divided test tasks according to the participants' background and expertise. Afterwards, the academic team and the industry researchers drafted the user test plan asynchronously. Industry researchers and managers defined the scenarios and task list tests to mimic the company's development process in the virtual environment; likewise, industry researchers managed the practicalities of the user test in the company: permits' management, scheduling of participants, and equipment set-up. Academia completed the software updates, training video, and an online survey. The final planning meeting consisted of the academic team and industry researchers to confirm the roles and scheduling for the user test and means to share the collected data. More concrete descriptions of the user study methods, procedure, participants, and results are presented in sections 5.2 and 5.3.

7. Data Analysis was performed separately by both academia and industry research groups. Industry researchers collected and prepared for analysis the notes made by observers and the facilitator of the user tests; in total, 268 comments were gathered and listed in an Excel file. Further, the comments were tagged by the following categories: *specific application features, such as tool-related comments, overall user experience (negative and positive), suggestions,* and *the impact of the application on the participant's working methods.* The data from the survey were analyzed by academic researchers using descriptive statistics. The resulting data were combined and utilized to form a discussion in a **series of collaborative workshops** between academia and industry research teams. The focus of collaborative work was to identify the weaknesses of the current design and plan the modifications of virtual spaces and virtual tools based on the user study findings. In addition, it was critical to establish a common understanding of the future system development and a plan for the next user study and related requirements.

4 COVE-VR: System Design

The *COVE-VR* is meant to facilitate department-to-department collaboration in a VE, with a focus on digital content creation and enhanced synchronous and asynchronous communication. This section presents the final design of the system: the virtual environments and virtual tools available within. Two virtual environments were created to support the development of maintenance methods and related documentation tasks, shown in Figure 3. The *Lab* VE is a small working space for primarily individual work, and it replicates a real maintenance site. The *Showroom* VE is a big-sized working space for individual and collaborative work. It is designed as a meeting room and consists of two floors. This space can be used for in-depth analysis of 3D models on the pedestal via a dedicated panel located on the wall. Using this panel, the models can be scaled, rotated, and moved horizontally up to the second floor. The models can be also disassembled (Figure 3, bottom); the parts of the models can be highlighted and removed. The user can cancel the last action or restore the model to its original state.

Seven virtual tools were deployed to enable documentation content creation in the VEs; the tools are opened from a touchpad-activated radial menu. The (1) *TextBox Tool* is used to create text notes via speech-to-text or typing (Figure 3, top); the notes are left in the environment in the form of an open text window or message bubble. Text notes can be exported to the desktop as a document in the order of creation with a timestamp and author name. The (2) *Camera Tool* can record videos and capture photos in the VE, which are saved to the hard drive. To work with a 3D model, the user can open it with the (3) *Model Placement Tool* from the list of available models. With the (4) *Measure Tool* users may measure distances in the VE. The tools and models can be deleted with the (5) *Delete Tool*. The (6) *Grid Snipping Tool* can be used to lock the movement of the models to grid points or set angles, and it also has a precision mode which reduces the range of movement for more control over object manipulation. After completing the work, all VR objects can be saved for the next user with the (7) *Save World State Tool*.

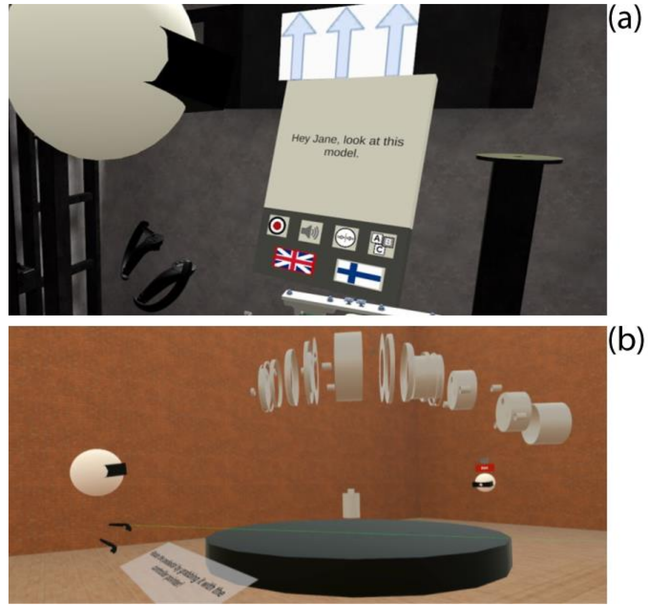

Figure 3. The Lab VE with TextBox Tool opened (a) and the Showroom VE with a disassembled 3D model (b).

5. System Evaluation: Methodology and Results

This section presents the methods and procedures of the COVE-VR system evaluation in two rounds, followed by the results on perceived value and performed collaboration process. Since this article is focused on the process of collaborative development and the evaluation of employees’ subjective perceptions, it does not include the description of methods or findings related to the system design.

5.1 Online Survey with Company Employees

The survey was open during September 2020. The link to the survey was shared by the industrial researchers via their internal mailing channels. As a result, we received 38 responses, 18 of which were complete, and thus, suitable for analysis; the rest were filled in only partly. Responding to the survey took on average 48 minutes. The respondents were aged from 26 to 62 (M = 36.5) and only 2 of them were female. Most of them (14) hold a bachelor or master’s degree, while the rest had a high school or vocational school degree.

By country of residence, six were from Finland, four from China, four from India, and the rest were from Australia, Netherlands, Germany, and Malaysia. Nine of the respondents represented the Maintenance Development department, five represented the Technical Documentation department, and two were from the Learning and Development department.

The survey was created via the *LimeSurvey* tool and it incorporated two 360-videos of virtual environments, videos with voice-over to demonstrate the usage of virtual tools, pictures of icons, and a variety of questions. The survey consisted of six sections, however, in this article we disclosure the materials only from three of them: 1) *background information*, 2) *overall system perception*, and 3) *COVID-19-related statements*. The background data section collected the respondents’ age, gender, role at work, previous experiences of using VR/AR applications, and participation in the previous survey on feature prioritization. The overall system perception was collected in a form of 12 statements answered on a 7-point Likert scale and 5 open-ended questions on drawbacks, benefits, and ideas related to working and collaborating in VR. The COVID-19 section (5 statements) collected subjective perceptions on how the pandemic situation had changed working activities and how the designed VR system could address it.

5.2 User Study with Experts

The study investigated subjective perceptions of the system and its usefulness in accordance with the industrial tasks. The study was conducted at the company’s premises in Finland; facilitated and remotely observed by the industry researchers due to COVID-19 restrictions. In total, there were one pilot test, six in-person user tests, and one remote user test facilitated for a participant located in the USA. An HTC Vive Pro headset with controllers was used for the testing procedure. The sessions were live-streamed and recorded using a USB camera to capture the participants' actions in the virtual reality room together with the participants' point-of-view from the VR. Lastly, a GoPro Hero 3 camera was set up to record the overall room set up as an offline backup.

Methods. Both qualitative and quantitative data were collected during the user study via observations, an online questionnaire, and interviews. The methods of data collection were created in collaboration between the academic and industry researchers. An observation form was created to ensure the systematic gathering of users' general state of mind, workflow procedures, emotions, technical issues, suggestions, and improvement ideas. The online survey for the user study was based on the previous online survey to compare the results. Additionally, the SUXES questionnaire on users' expectations and experiences [25] and statements on immersion and presence in VR, adopted from Presence Questionnaire (PQ) [28], were added. The semi-structured interview consisted of 10 questions: half of them were created by academics with the focus on user experience, user interaction with the application, and the exploration of system functionality; and half were created by the industry with the focus on department-to-department collaboration and the implication of VR use to the users' ways of working.

Procedure. The procedure started with an introduction to the study and signing a written consent for participation. Next, the participants filled in background data and watched the demo video, describing the purpose and functionality of the system. After, they filled in the SUXES questionnaire on system expectations. Next, the participants had a training session with the application and proceeded to the actual user study tasks in VR. The tasks and content in VR were different for maintenance method technicians and documentation technicians. For maintenance, the focus was on developing the content with the help of tools. For the documentation department, the focus was on working with already created content. Throughout the user test sessions, the facilitator encouraged the "think-aloud" method to gain insights [3]. After the tasks in VR were performed, the SUXES part on experiences was filled in, followed by other survey parts and an interview. On average, the procedure took 2 hours and 17 minutes: the length of the procedure may be explained by the long preparation process and extensive interviews, which took at least 45 minutes. After the user tests were completed, the industry researchers conducted a debrief of the session and shared all the materials with the academic team using an encrypted online drive.

Participants. Since the user study procedure was time-consuming, a relatively small group of target users were approached for testing purposes. In total, *seven target users*, aged from 27 to 57 (M = 41), participated in the study. Four represented the Maintenance Development department (two novice and two expert users with an average of 9.3 years of experience) and three represented the Technical Documentation department (two experts and one novice users with 14.3 years of experience on average). Five participants were male. Six held a bachelor's degree or similar. Six participants were residents of Finland and one residing in the USA. Finally, all the participants from the Maintenance Development department had responded to the previous survey on system design; and further, two of them had responded to the initial survey on feature prioritization.

5.3 Combined Results of the Evaluation

This section introduces the results of the collaborative iterative user study from two angles. Based on the comparison of the online survey and user study findings, supported with the interview responses, we demonstrate the value of the system to the end-users. Next, we reflect on the performed process of academia-industry collaboration.

5.3.1 User Perception of the system

The results of the online survey and the user study with experts were positive without a big variance in responses; the survey helped to verify that the design corresponds to the needs of the employees and business goals with two focus groups, whereas the user study allowed more in-depth evaluation of the system design with a focus on interactions and content creation. Based on the survey, the concept of the system was found to be a safe and convenient approach to ease up the remote communication and collaboration of departments. As one of the responders commented, this system *"can make the cooperation in many points easier"*, as it allows to "*spontaneously work together on certain things, independent of location"*. The major concerns about the system were (1) the price and still limited ergonomics of the VR headset and (2) the level of realism and preciseness of the virtual spaces and 3D models, which would be critical for efficient work process. However, none of the user study participants shared concern on the level of realism one of them even commented that "*the graphics were realistic*".

As can be seen in Figure 4 the system was perceived extremely well overall. Still, there is a small decrease in the perception of the system between evaluating it based on videos (in an online survey) and based on interacting with the system (user study). Most of the target users believe that the potential of VR can benefit the company's work processes and support the idea of transferring work processes into VE ($Mdn_1 = 7$, $Mdn_2 = 6$). Only one respondent of the survey was neutral, and one user study participant slightly disagreed that VR is flexible to be used for the company's purposes ($Mdn_1 = 6$, $Mdn_2 = 5$). Most of the participants would like to use VR to perform their tasks ($Mdn_1 = Mdn_2 = 6$) and feel enthusiastic about it ($Mdn_1 = 6.5$, $Mdn_2 = 6$). Further, all the respondents agreed that the system design is useful for the company (Mdn_1

= 7, Mdn_2 = 5); they think that VR would motivate them (Mdn_1 = 6, Mdn_2 = 5) and increase their performance (Mdn_1 = 6, Mdn_2 = 5). Participants also mostly agreed that the system would make their work faster (Mdn_1 = 6, Mdn_2 = 5), safer (Mdn_1 = 6.5, Mdn_2 = 6), and easier (Mdn_1 = 6, Mdn_2 = 6). Finally, all of them believe that VR technology can enhance department-to-department collaboration. Further, most of the survey respondents agreed that COVID-19 affected their working practices (Mdn = 6) and expressed the desire to use *COVE-VR* in addition to existing desktop applications, like Teams (Mdn = 6). All of them agreed that the system would make their work tasks easier and faster when working remotely (Mdn = 6).

As a result, the system evaluation demonstrates that the system design addressed the employees' needs and is sufficient to support the work tasks of both maintenance methods developers and documentation experts. Apart from collaborating in the VE, some participants expressed the desire to export and share the notes and pictures from the VE to other means of communication, e.g., email. One of the participants from the documentation department commented: "You could take a picture of the component and the note that was written and share it via email for instance to have a different way of communication with designers and methods developers". Also, many other benefits and use cases with the VR system were mentioned, for instance, training and learning based on 3D models, maintenance method reviews and tests, international meetings, and demonstrations. Moreover, for demonstration purposes, the presence of only one person in VR would be sufficient to benefit from enhanced visualization capabilities of VR when presenting products or 3D models; the others may be present via video conferencing.

5.3.2 Academia-Industry Collaboration: Roles and Processes

Four industrial researchers (R&D), three managers and around 15 company employees (with 1-20 years of domain experience) were included throughout the development process. The R&D team was the *core group to collaborate with academia:* They coordinated communications with academia and facilitated decision making inside the company. They also contributed to all the design and development process phases: the group outlined and shared company processes and related materials, facilitated most of the collaborations events, and contributed to the research methods and system design iteratively. In addition, the company involved *an extended team of company employees* to provide a wider viewpoint for decision making. The extended team was composed of people with different areas of expertise, who were involved when needed to provide an alternative or added vision from the company's employees and verify decisions.

As for other industrial groups, three managers and four target users participated in the first collaboration event, which helped to identify users' needs on a general level and the perspective of the management team and their vision for the company's development.

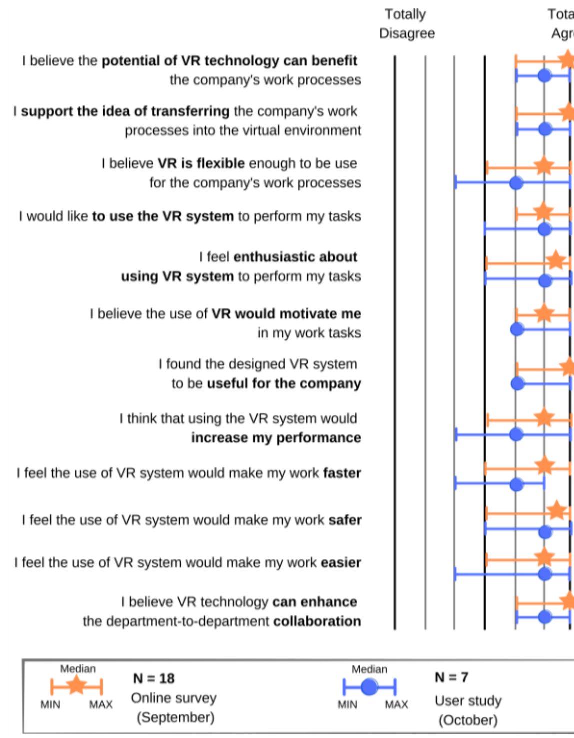

Figure 4. Results of system perceptions in the two phases.

Further, six target users from two countries participated in the follow-up workshop to investigate user-related aspects and system requirements while exploring working context and tasks. The identified system requirements were further prioritized by two managers and four target users. That helped to establish the design direction and include opinions of both actual users and people with decision-making power. All the above-mentioned activities, which relate to the first phase of the user-centered design process, resulted in the creation of personas, user workflow and scenarios and system functionality together with the list of features to be implemented to accomplish these scenarios. The system was further developed by the academic research group; the industry researchers' involvement via a series of remote meetings and demonstrations were held to assure that the design complements the requirements.

Then, the designed system was evaluated via online surveys (due to the COVID-19 pandemic). Since the online survey was anonymous, the concrete number of managers and employees who contributed is not known; the survey was shared with seven managers and 27 target users, which resulted in 18 complete fill-ins. However, this process helped us to verify the chosen design solutions (e.g., virtual environments and tools) and to measure the employees' perception of the system's benefits for the company prior to the actual user study. Finally, seven company employees participated in the user study, which leads to an in-depth analysis of the system efficiency and usability, resulting in further system development. All data collection forms were collaboratively and iteratively designed by the academic and industrial researchers together. Thus, both parties were able to extract knowledge for their own purposes.

6 Discussion

This study introduced an academia-industry collaboration process with the goal to develop a VR system, which addresses industrial needs to enhance department-to-department communication. The article demonstrates the design process of the *COVE-VR* system and presents company employees' perception of the system, based on the data from the online survey and the user study. The article further reflects on this process and summarizes all performed activities under ***a process-oriented framework for remote academia-industry collaboration*** (Figure 1), generalizable to other cases of joint activities between industry and academia.

Our process-oriented framework details the methods and practicalities of maintaining experience/knowledge sharing and transfer between the academic and industrial partners throughout the user-centered design and development process in a remote and agile manner. In contrast to existing models, such as the Certus model [17] that addresses the collaboration from the practicalities of role sharing, commitment and knowledge generation, our framework provides clear steps and methods to maintain such practicalities. By adopting this framework, academics and industry representatives may pave the way toward smooth and efficient collaboration while minimizing the challenges [11]. The clarity of operations and enhanced communication, promoted by the framework, allows establishing common objectives and work methods, which in turn, minimizes organizational issues [6] and harmonizes the pace of the development process [11]. Continuous and constant communication, and follow up between the academic and industry activities aimed to produce rapid results to cope with the industry's frequent delivery requirements, at the same time accelerating the research process in the academia [22].

The results on the system perception demonstrate a high relevance of the designed solution to the target users; most of them found the system beneficial for collaboration and for the company's needs, despite a few interaction issues. The findings indicate the success of the performed collaboration process; joint activities resulted in the correct determination of industrial needs and system requirements. Furthermore, the system design, which combines virtual environments and virtual tools for collaborative content creation, can be utilized in any other fields, related to product development and corresponding service activities with a focus on extensive documentation (e.g., construction, heavy machinery, aircraft, and transportation). *COVE-VR*, or a similar system, can advance the communication between employees and departments while providing means of easy content creation. Furthermore, our results indicate that such systems would advance the work processes in the situation of forced remote work and minimize the issues of productivity and efficiency.

Our system concept could also bring benefits to multinational companies, who already utilize 3D CAD models for their operations. Such a system potentially reduces costs and the time span of industrial operations by providing an environment to efficiently use the existing company's materials and create new forms of it. Furthermore, our findings indicate that not every employee would require a VR headset for personal use to gain benefits from VR visualization capabilities. The presence of one person in VR would be sufficient to demonstrate 3D models and related issues, which can be further streamed or shared in a video format.

6.1 The Benefits of Collaboration

The collaboration between academia and industry provides clear benefits for both parties. In brief, for this case study, academia's expertise in user experience and interaction design, as well as methodological knowledge of conducting user studies, proved invaluable to the company. Furthermore, prior experience with and knowledge of VR technologies and associated CVEs including the design and development of such systems from research and practical perspectives helped to develop the system without massive expenses. The company contributed by bringing in real-life use cases and associated challenges, in addition to existing real-life products and materials (3D models). Moreover, the company expertise in shared maintenance and maintenance development, documentation and localization, VR training and process management, as well as multicultural, global collaboration settings enabled a test environment to touch all these aspects.

From academia's perspective**,** such collaboration *increases the relevance of research* and opens new research directions, as has been discussed in previous works [11]. The knowledge sharing and transfer with industry provides an opportunity *to gain a clear understanding of the gaps and challenges* to be addressed as well as an industrial context and related user experience processes to investigate. The *access to actual target users*, which would have not been possible without the collaboration, resulted in the retrieval of realistic and relevant data for the analysis. These demonstrate a 50% response rate to the online survey, whereas it would be close to zero in case the academia would try to collect this information on their own from relevant respondents.

Furthermore, the *user study with actual target users* would not be possible at all without the involvement of the industrial R&D team. Shared timeframes and scheduled meetings to elicit feedback from the industrial researchers resulted in a more agile design and development process at the academia premises, while constant feedback ensured system pertinence. The collaboratively designed VR system (relevant to actual users) may be utilized for further experimental research to investigate multimodal interactions, presence, immersion, and collaboration aspects in VR in similar or other contexts.

From industry's perspective, such collaboration provides *knowledge expertise* and *additional resources* for the company's development. Furthermore, research projects provide an opportunity to test and validate in more detail, and to *better understand companies' own user needs and requirements*. Experimental studies are challenging in an industrial setting because of limited resources. The traditional way of working in the industry does not always allow that much time to be spent on research [11] due to tight project and production schedules. It is also impossible to recruit and employ the best experts from every area of expertise in industrial companies. Academia with its numerous universities have the best experts with the latest knowledge and peer-reviewed and validated research. Therefore, *collaboration with academia increases the possibilities of doing research and experiments in companies*. Acquiring state-of-the-art knowledge from academia together with experimental studies help companies to prepare for the future as one of the industry leaders. In-depth research results support the fast-paced development work done inside the company, driving the progress and innovation further, and strengthens the company's brand as an innovative company.

Furthermore, industry-academia *collaboration allows the industry to publish* and share their knowledge with others. Traditionally, research done in industrial companies is rarely published even if it does not contain any core business information about the company. Therefore, any development done remains in the companies and is shared through informal channels or benchmarking only. This is true even when the results concern non-IPR work or best practices. Collaboration with academia shares the results further, benefiting a wider audience. Additionally, research done in industrial companies is, in many cases, done with very specific company needs and use cases in focus. When working together with academia, it is more natural to think outside of the company box and generalize the ideas to a different level.

6.2 Practical Suggestions for Academia-Industry Collaboration

Based on our collaboration process, we framed a list of practical suggestions to support the proposed framework and enhance the communication and knowledge sharing between academia and industry:

1. Define roles, procedures, and industrial focus groups. Despite the collaboration mostly happening between academic and industrial researchers, our results demonstrated the value of including the management team and other employees throughout the process. Hence, we encourage identifying relevant (industrial) focus groups and keeping them involved via academic practices. Further, identifying the roles and responsibilities of each party and agreeing on the procedures would address not only the possible organizational problems and the lack of commitment [11] but also transaction-related barriers of collaboration [6].

2*. Establish trust and shared understanding*. To overcome orientation-related barriers of collaboration [6], it is critical to exchange and clarify each party's own goals and expectations for the collaboration. Hence, we suggest initiating a collaboration process with an activity (in our case *a kick-off meeting*), that would include all relevant focus groups to ensure that everyone's perspective is communicated. Further, as the result of such activities, we suggest establishing shared goals, objectives, and timelines, including long-term and short-term plans, to overcome misunderstandings while harmonizing the pace of joint work [11, 22]. Further to promote trust and openness while avoiding transaction-related issues [6], we suggest utilizing both official and unofficial channels of communication (e.g., email lists and Teams chats) as well as a shared storage option with equal access (e.g., OneDrive).

3. Remote participation and iterative feedback. Based on the success of our remote demonstrations and feedback sessions when developing *COVE-VR*, we highlight the importance of sharing unfinished work to elicit feedback and apply modifications iteratively from the earliest phases. Remote knowledge and experience sharing can be facilitated via traditional conferencing tools (e.g., Teams), where the progress of development can be presented via videos or streaming from VR. The lack of interaction may be addressed via an accurate spoken description of how the system is operating and open discussion.

7 Conclusion

In conclusion, our academia-industry collaboration process on the joint software development of the *COVE-VR* system demonstrated promising results. In a collaboration between academia and industry, we performed a user-centered design process and developed a VR system that enhances the remote collaboration of departments from different sides of the world and delivers virtual tools for content creation.

The system was evaluated through an *online survey* (18 respondents from the company) and a *user study (*7 target users). Our findings show a very positive perception of the VR system and the relevance of the design in accordance with the industrial needs. Virtual reality may not only enhance the communication between departments, but also facilitate the generation of digital content (e.g., text, pictures, and videos) as a result of this remote collaboration. Hence, VR has the potential to decrease development time and costs while increasing the company's overall productivity. Nevertheless, being limited to a single company case, we acknowledge the need to investigate the use of CVE in similar contexts.

Finally, with this article, we promote the collaboration between academia and industry and provide a *process-oriented framework* and *practical suggestions* on how to maintain joint activities. This work presents the benefits of including various industry groups in the research activities and demonstrates a positive perception toward VR.

ACKNOWLEDGMENTS

This research was carried within the HUMOR project, funded by Business Finland. We thank all KONE employees for their valuable input to the development process. We also thank research assistants Topi Nieminen and Jesse Sydänmäki for their contribution to the COVE system development process.

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