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Implications of Virtual Reality on Environmental Sustainability in Manufacturing Industry: A Case Study

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Abstract

Research on Virtual Reality (VR) in manufacturing is rarely driven by environmental sustainability. This paper explores the feasibility of developing VR technologies to reduce environmental impact, drawing from a case study in an automotive company. We developed a VR demo to support the communication for design review between the technology centre in Sweden and the manufacturing site in China, thus reducing travel frequencies. This reduction was verified through user experience and feedback from focus group discussion and questionnaire. The results show a reduction of travel frequencies for design review, therefore contributing to environmental sustainability.

Keywords: environmental sustainability; Virtual Reality; manufacturing; VR; sustainability; case study.

1. Introduction

Manufacturing companies are increasingly prioritizing environmental sustainability due to their growing contribution to energy consumption and CO_2 emissions. Meanwhile, Industry 4.0 technologies play an ever-increasing important role in evolving manufacturing towards environmental sustainability, in addition to improving the operational performance through increased productivity [1]. Virtual reality (VR), as a promising Industry 4.0 technology, has the advantages of supporting decision-making by visualization and experience, especially in international companies with distributed functional teams [2,3].

According to Chang et al (2017) and Rocca et al (2020), VR could be adopted to improve the disassembly and remanufacturing processes, thus contributing to Circular Economy (CE) by bringing back the used materials and components to the product lifecycle with a higher efficiency [4,5]. The laboratory application case given by Rocca et al (2020) presented a VR-based tool, which enabled a better materials recovery through simulating and optimizing a disassembly process before replicating it on practice [5]. However, there are only sparse case studies focused on exploring environmental sustainability implications of VR technology in manufacturing context. Hence, this paper aims to fill the above-mentioned gap by answering the following question: what are the implications of VR applications on environmental sustainability in the international manufacturing context?

In this research, we carried out a case study in a globally distributed manufacturing company by looking into the development of two VR-based interactive design approaches. Through demo development and testing, interviews, focus group discussion and questionnaire, both the possibilities and challenges of implementing VR towards environmental sustainability were identified. With a better understanding of where and how VR implementation could support the reduction of environmental impact in manufacturing processes, practitioners will be able to harness and implement VR technology in a more environmentally friendly manner.

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Considering the lack of studies on environmental impact of VR implementation [5,6], this study also identifies the need of exploring the implications of VR on environmental sustainability, especially in the era of Industry 4.0 evolution.

2. Frame of References

2.1. VR in Manufacturing

According to Latta and Oberg (1997), VR is an "advanced human-computer interface that stimulates a realistic environment and allows participants to interact with it", that is, it establishes a relationship between the participants and the created environment [7]. Similarly, Berg and Vance (2017) defined VR technology as a set of technologies that allow people to have an immersive experience of the world beyond reality [8]. In general, there are five categories of setups from which VR facilities utilize one or more [2,8]:

- Desktop system.
- A large projection screen (i.e., powerwall).
- Multiple connected projection screens (i.e., CAVE system).
- Stereo-capable monitors.
- Head-mounted displays (HMDs).

With the human experience at its core, VR intends to mimic how we interpret the world around us through the information processing system, and convinces us that we feel physically located within the virtual world [8]. Nowadays, VR technology has become common in industry and its value has been recognized for technology improvement and cost reduction [3]. The most frequent application areas of VR technology in manufacturing are maintenance and virtual training, of which virtual training is mainly used to support workers in assembly tasks and provide an environment with higher safety [8], enabling higher precision [9] and shorter cycle time [10]. Furthermore, the immersive environment provided by VR supports decision-making on product design, layout planning, and planning of activities for resource matching [2,8,11].

2.2. VR and Environmental Sustainability in Manufacturing

Environmental sustainability is defined as "the development of meeting the resource and services needs of current and future generations without compromising the health of the ecosystems that provide them" [12,13]. Environmental sustainability in manufacturing relates to stabilizing the balance between manufacturing activities and their impact on our living environment. Furthermore, the U.S. Department of Commerce defines the concept of sustainable manufacturing as "the creation of manufactured products that use processes that minimize negative environmental impact, conserve energy and natural resources, safe for employees, communities, and consumers and are economically sound" [14].

VR technology in manufacturing has both positive and negative impacts on the environment [6]. On the one hand, VR contributes to CE through the digital optimization of disassembly processes, thus increasing manufacturers' capacity of recovering valuable components and improving material restoration [5]. Moreover, VR increases resource and energy efficiency through enhancing the level of understanding and communication efficiency, as well as replacing physical products [15–17]. On the other hand, the energy consumption during the production and use phase of VR technology brings a negative impact on the environment [16]. As an ICT tool, the lifecycle of the VR device, which includes the headset, sensors, controller wands, motion trackers, displayers and etc., also adds an extra burden to the environment [18].

3. Method

The case study was conducted in an automotive company, whose research and development center is located in Sweden, and manufacturing plants in China. The choice of this international company with distributed functional teams had two reasons: (i) the case company was motivated to develop and implement VR technology to bridge the different teams; (ii) this case study could enlarge the advantage of adopting the multi-user VR system in interaction design. In general, VR demo development and testing, interviews, focus group discussion and questionnaires were used to collect data, as Figure 1 shows.

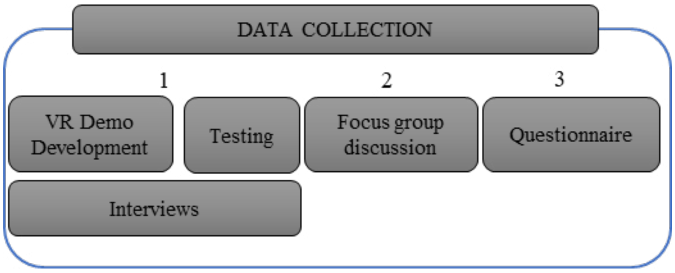

Fig. 1. Case study phases

3.1. VR Demo Development and Interviews

To start with, a VR demo development was done in close cooperation with the company. The selection of assembly operation, consideration of motions, and development platform were agreed with the company through rounds of discussion by meetings and emails. The input data for demo development was captured on site of the Chinese manufacturing plants with 3D laser scanning technology, which provided a realistic version of virtual representation of the manufacturing environment. Unity3D was chosen as the development platform to develop the desired functionality by integrating different data sources[19]. Unity plugin PUN2 was adopted to synchronize different users and handle the network [20]. In addition, the demo used HTC Vive headset throughout the study [21].

A pilot version was developed to test the feasibility of the demo concept and collect feedback for further improvement. It was firstly tested between Gothenburg in Sweden and Gaithersburg in the United States with fellow colleagues. It was then followed by a second test carried out in Sweden with external participants from FCC (Fraunhofer Chalmers Center). Both tests performed the intended design review task in VR and had a discussion session afterwards for further improvement.

The second version was focused on increasing the connection reliability and minimizing the latency of synchronization. Customized user avatars were included as an additional feature from the pilot workshop. The improved demo was tested in the case company in Gothenburg, with 14 participants from different departments including process engineers and the vice president. After the test, feedback was collected by filling out a scale-rating survey regarding their testing experience.

Meanwhile, 15 interviews were carried out to identify the most potential areas for VR implementation in the case company. The interviews were conducted with people who had been working with VR in the company, and the questions included some identified areas of application, which were summarized by cross comparing the areas of VR application between literature and the case company. The same set of questions was asked to all interviewees, and the answers were summarized after each interview and sent back to the interviewee to clarify possible misunderstanding. All the interviews took place at the case company, and each one took approximately one hour.

3.2. Focus Group Discussion

Combining the testing feedback and the interview results, a focus group discussion was held with the engineering department to discuss the biggest potential of VR application contributing to environmental sustainability. The summary of the discussion was used as an input to design a questionnaire for verification, in order to collect feedback from a broader scope of users. The questionnaire was administered right after the demo testing of the second version.

3.3. Questionnaire

The questionnaire was designed with three parts: general information, questions regarding traveling and other influences from immersive VR. General information included the role in the company, the work experience with VR in terms of length and frequency, and user-experience. The second part included questions about the traveling frequencies and purpose, the user experience with the regular technologies, e.g., Skype, compared to using VR to replace traveling. The third section of questions aimed to get some insights about other possible impacts of using VR.

The collected data was discussed and reviewed with the company at each key stage to avoid bias and misunderstanding, including the demo development, the interview summary, and the questionnaire design.

4. Results

Findings from each phase of the case study are presented as follows.

4.1. Demo Development

The pilot version of VR demo was developed as shown in Figure 2, with a realistic representation of the manufacturing environment in China.

Fig. 2. VR demo view from the pilot version

It was then tested with colleagues in the U.S. and external partners in Sweden. From the after-testing discussion, the potentials for further improvement were identified in the connection stability and quality of real time synchronization, especially in eliminating latency. Based on the improvement suggestions, a second version of demo was developed as shown in Figure 3.

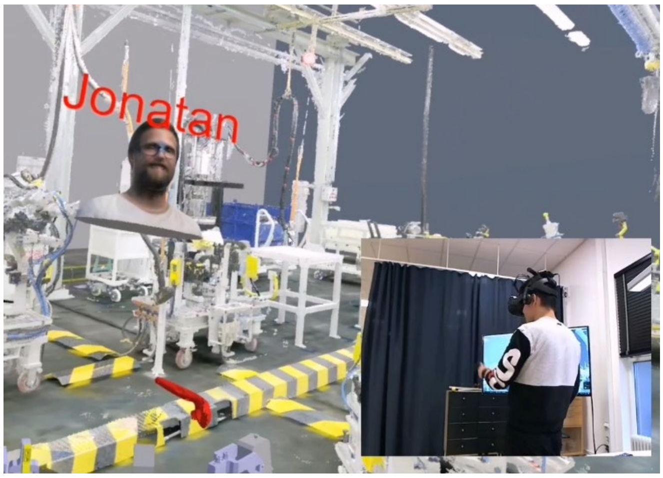

Fig. 3. VR demo of multi-user view from the second version

The second demo performed in a higher quality with simultaneously appearance of customized user avatars and instant movement in the virtual environment.

4.2. Interview Results

17 potential areas of VR application were identified within three main areas as shown in Table 1: Analysis, Communication and Visualization. Analysis is described as the area of use that is mostly connected to analyzing ergonomic issues and others. Communication is described as the area of use that mostly connects to enabling better communication, and Visualization is described as visualizing matters and issues to enhance understanding.

Most of the activities could be done with standard VR equipment that is available today at the case company, as marked in green in Table 1. The other activities marked in yellow require planning and will be in place within one year.

Table 1. Identified potential areas of VR application at the case company

Analysis	Communication	Visualization
Assembly geometry assurance	Claim support	Concept verification
Ensure safety of operator	Collaboration	Experience cell layout
Equipment verification	Create work instructions	Experience factory layout
Ergonomics	Discussions	Experience line layout
Reachability	Meetings	Perceived quality
Study processes	Status reporting	

A large amount of long-distance communication is required between Sweden and China at the company. However, as some interviewees claimed, the discussion on technical details through screen sharing sometimes limits the communication quality, thus leading to a need for business trips. These trips mainly occur to ensure the understanding between different parties, especially on areas of testing, including car crashes, perceived quality, assembly precision and production processes.

4.3. Focus Group Discussion

With the feedback from demo development and testing, as well as the interview results, the focus group discussion with the technical leaders was held in several rounds. Traveling reduction was identified as the area of VR application with the highest potential towards environmental sustainability. Reasons for traveling were listed, together with the time point of the trip throughout the development process. The main reasons of traveling are listed as follows:

- Relations/networking
- BOP & Plant verification
- Simulation verification
- Education
- Fixture design review
- Production support
- MTO review
- Product support
- RFQ support

The spreading of time point for traveling was analyzed as Figure 4 indicates. Another major outcome from the discussion was to present the potential of replacing physical traveling by communication through VR. This replacement was then marked in green, comparing with the original traveling needs marked in orange (business as usual) in Figure 4. Relationship/networking, RFQ support, MTO review, product support, fixture review, production support and BOP & Plant verification were identified as the areas with the highest potential for this replacement.

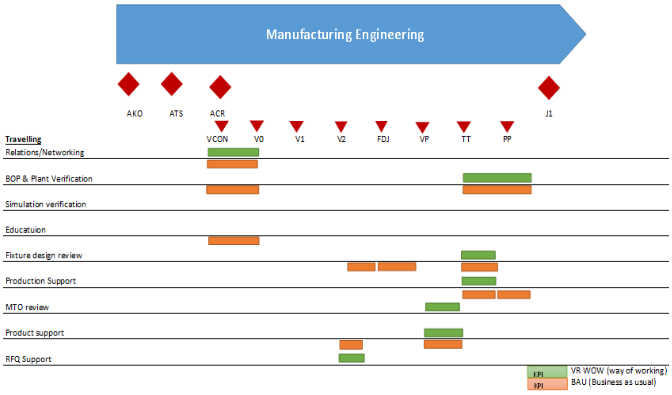

Fig. 4. Traveling throughout the development process

4.4. Questionnaires

14 responses were collected by filling out the questionnaire at the case company, of which 10 were by engineers and four were by managers. 12 out of these 14 people had traveled to China more than once in the past 12 months, with an average number of two times per person (as shown in Fig. 5).

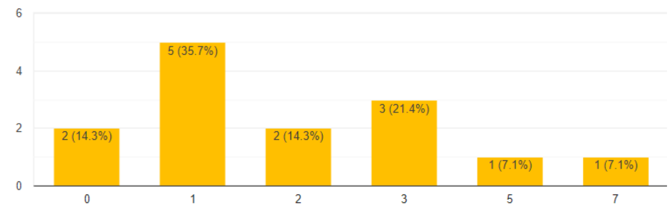

Fig. 5. Travel frequency in the past 12 months

The main purpose for traveling to China was Relationship/networking and BOP and Plant verification with ten and nine replies, respectively. It was then followed by Production support and Product support, which had five replies each. Fixture design review was the next one on the list, with three replies (as shown in Fig. 6).

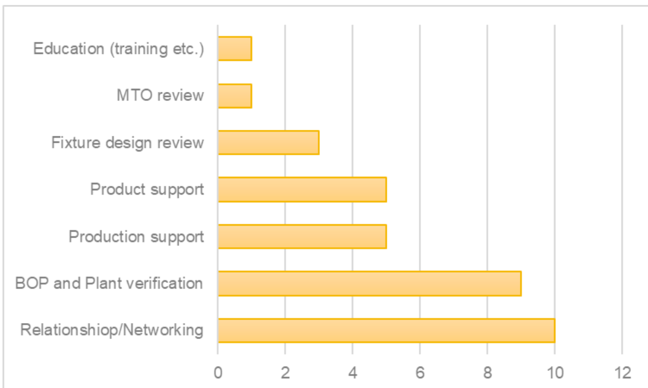

Fig. 6. Reasons for traveling to China

13 out of the 14 respondents thought VR could influence travel frequency more than 20%, two more positive responses compared to the reaction to regular remote communication tools, (e.g., Skype). Furthermore, 6 out of the 14 respondents thought VR could influence travel more than 60%, also two more positive responses than the regular tools (as Fig. 7 shows).

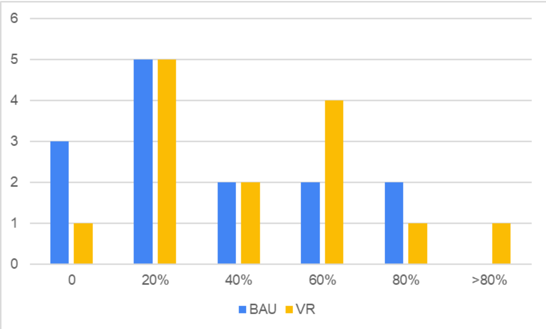

Fig. 7. Travel replacement potential by using other tools v. by VR

Moreover, 11 out of 14 respondents believed that the reduced travel frequencies could influence environmental impact positively, (e.g., CO_2 emission, climate change), in more than 20% (see Fig. 8).

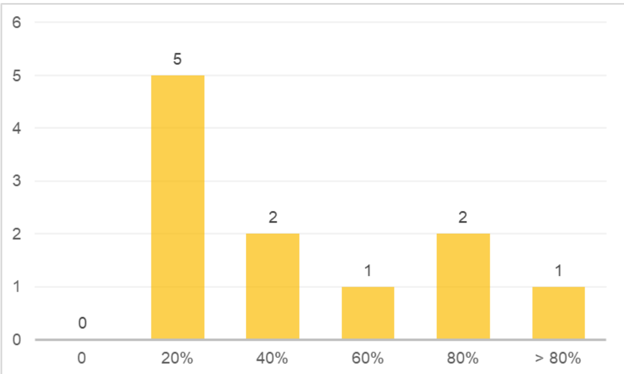

Fig. 8. Environmental impact influenced by reduced travels

When it comes to the influence of immersive VR on daily work, 11 out of 14 respondents held a positive attitude and believed that VR could make their work easier, of which two responded "much easier" (as Fig. 9 shows).

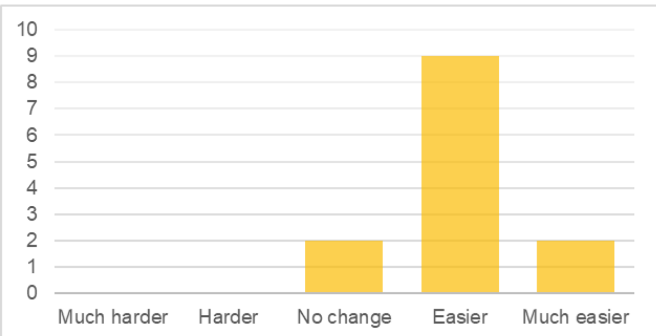

Fig. 9. Influence of VR on daily work

The main support brought by VR on work was mostly mentioned on the aspects below:

- Early study when developing prototype with less physical prototype required
- Better quality guarantee by detecting issues at an earlier stage
- Better accessibility to see product from different angles, thus supporting technical discussion
- Better understanding of manufacturing plants environment without physically visiting, especially on the detailed settings

In addition, the influence of VR on ergonomic evaluation was given a positive response from most respondents, mainly focusing on the improvement of reachability.

5. Discussion

This study was carried out in an explorative manner through developing a VR demo of a welding process and testing and collecting feedback from the users' experience, thus taking a step forward to identify the potential applications of VR in the reduction of environmental impact. In this study, the welding process in manufacturing environment in China was developed virtually as a VR demo and was experienced by users from the development center in Sweden. This application could potentially reduce the number of travels between China and Sweden due to product and process design and verification, which was claimed as the focused area of VR application according to Berg and Vance (2017) and Damiani (2018) [8,11].

The main support of VR application can improve the communication efficiency from the increased possibility of viewing product from different angles and with more details. The improved communication efficiency could replace the physical meetings and contact for technical discussions, thus enabling constant and frequent dialogue between developers and implementation sites. Hence, the instant feedback and changes on design modification could further improve product quality by detecting issues at an earlier stage, as stated by the questionnaire responses. The advantage of VR application in replacing physical visits could maintain and support the communication quality and efficiency.

As most respondents claimed, the reduced travels could contribute to environmental sustainability with less CO_2 emissions generated from international trips. However, reducing travels for communication and networking, especially at the beginning of a new project, is not feasible. VR technology could improve communication efficiency on technical discussion, especially when comparing with the regular distance-communication tools (e.g., Skype); and it could be described as stated on the questionnaire responses: "more efficient, and more fun". Nevertheless, it is not optimal to replace physical meetings that are meant for building up relationships. Furthermore, not all respondents were happy with the reduction of travels, as business travels could be one way to motivate employees by broadening their network and bringing personal values when gaining knowledge on different cultures [22]. It corresponds with what Kiel et al (2017) and Chen et al (2020) stated, that the three pillars of sustainability are interconnected [1,6]. When we look into the environmental impact of VR application, the social aspect shall also be acknowledged. Most of the respondents from both interviews and questionnaires were comfortable with the use of VR headset; nevertheless, the user experience varies between the individuals, which shall always be considered when implementing VR to replace physical travels.

Similarly, the investment on VR device and education is another pivotal aspect to consider. Fortunately, the application costs of VR have descended dramatically in the past ten years due to the rapidly improvement of VR technologies [3], which promotes a broader recognition of VR application.

This study attempts to fulfill the gap of exploring the implications of VR on environmental impact with an industrial case study [16], which is still rare in published articles. Therefore, it is worth to explore further the overall implication of VR applications in reducing environmental impact, including the quantitative assessment of the environmental impact of the technology hardware [6]. Furthermore, a second study in a couple of years could be carried out to verify this study and explore other potential areas, when more applications have been identified and implemented in place.

Some limitations could be summarized as improvement input for future studies, including the scope this study. It was carried out only within the engineering department at the case company, which resulted in a limited number of responses. Another limitation could be the qualitative approach of this study, which requires further validation with quantitative data, such as the actual impact on the environment, including the technical lifecycle of VR.

6. Conclusion

This case study was carried out in an international automotive company with development center in Gothenburg, Sweden, and manufacturing plants in China. To explore the implications of VR technology on environmental sustainability, demo development, testing, interviews, and questionnaires were performed. The findings conclude that the application of VR in technical discussions of product and process design could replace physical visits and contacts, thus reducing the travel frequencies. The reduced travels could contribute to environmental sustainability with the potential of reducing CO_2 emissions. The advantage of VR application in replacing physical visits could maintain and support the communication quality and efficiency, especially under the constraints imposed by the current Covid-19 pandemic. Future work could go further in exploring the quantitative impact of VR on the environment; as well as it could deepen in a broader scope of study, such as involving more participants, and other potential application areas.

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