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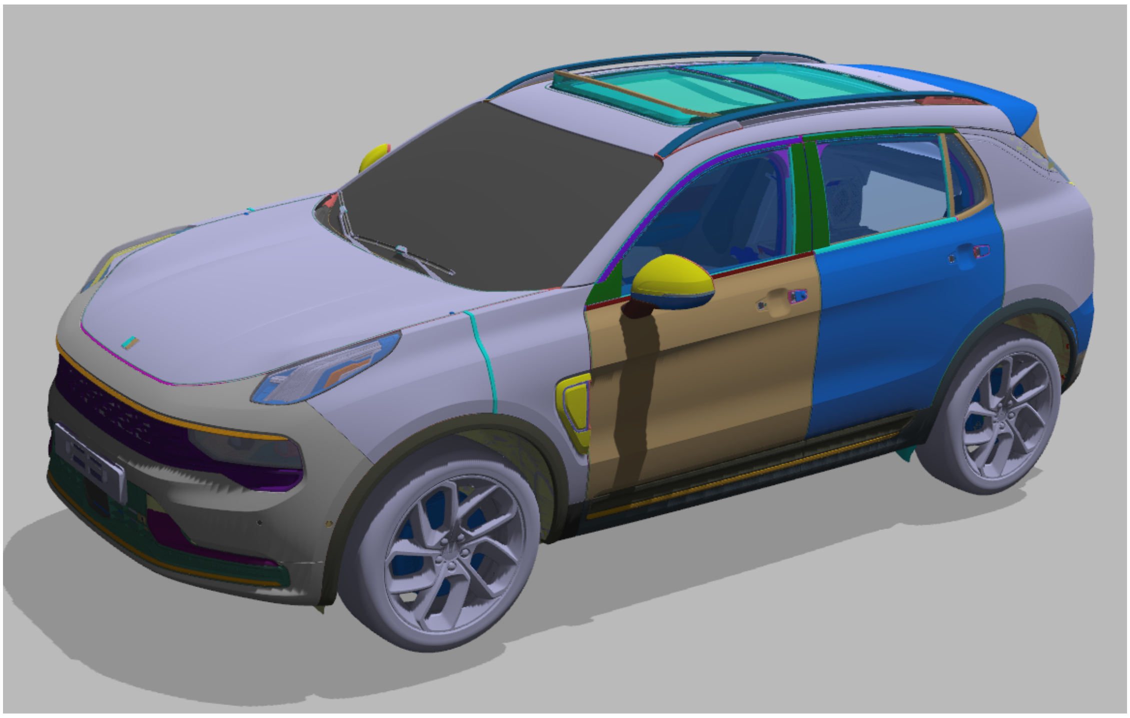

Design Meetings enabled by IPS

Case study with Pilot Test Demonstrator in Industry

Master's thesis in Production Engineering

Ludvig Herman & Jacob Johansson

DEPARTMENT OF INDUSTRIAL AND MATERIALS SCIRENCE
CHALMERS UNIVERSITY OF TECHNOLOGY
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MASTER'S THESIS 2024

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LUDVIG HERMAN & JACOB JOHANSSON

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Master's Thesis 2024
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Abstract

The automotive industry is constantly growing and evolving to meet the demands of tomorrow. With this, many new technologies are introduced every year to enhance the vehicle development processes with the goal of making every step of the chain faster, higher quality and more cost-effective. This report investigates the current practices, challenges and potential advancements in design meetings within the automotive industry, specifically focusing on the integration of multi-user VR platforms.

Through interviews with engineers within the industry, we explore how these processes are conducted today, the difficulties encountered and the necessity for a collaborative multi-user platform. The findings highlight significant issues such as limited interaction capabilities, inefficient communication and the challenges of remote collaboration between global teams. The introduction of a multi-user VR platform is proposed to address these challenges by enhancing real-time collaboration, enabling manipulation of CAD models and improving overall understanding of design changes.

Due to the multi-user platform being too immature to do a comprehensive study on, a single-user investigation was made. A comparative analysis of VR and desktop simulations through workshops demonstrates the superior effectiveness and user engagement provided by immersive VR environments. VR simulations offer a more realistic and comprehensive understanding of assembly tasks, highlighting the real issues like spatial constrains and reachability which are often overlooked in desktop simulations. The study's T-test analysis confirms significant differences in knowledge acquisition and time estimation between the two methods, emphasizing the potential benefits of adopting VR technology in design meetings.

Keywords: Design meetings, Multi-user platform, Virtual reality (VR) simulation, Desktop simulation, Automotive industry, Industial Path Solutins (IPS), Case study

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Ludvig Herman & Jacob Johansson, Gothenburg, june 2024

List of Acronyms

Below is the list of acronyms that have been used throughout this thesis listed in alphabetical order:

AR	Augmented Reality
CAD	Computer Aided Design
DoF	Degrees of freedom
DRM	Design Research Methodology
DR	Design review
HMD	Head-mounted display
IMMA	Intelligently Moving Manikins
IMU	Inertial measurement units
IPS	Industrial Path Solutions
VBE	Virtual build event
VIM	Vehicle integration meeting
VR	Virtual Reality
XR	Extended Reality

Nomenclature

Below is the nomenclature of variables that have been used throughout this thesis.

Variables

$\bar{X}_1$	The first sample mean
$\bar{X}_2$	The second sample mean
s_1^2	The first sample variance
s_2^2	The second sample variance
n_1	The first sample size
n_2	The second sample size

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1 Introduction

The first chapter of the report aims to explain the background of the topic which is investigated and shine a light on the reason behind the report. Furthermore, it contains the research problem and the research question that should be answered during the study. The delimitations that will have an impact on the research are also explained to give a full explanation of the project's circumstances.

1.1 Background

In a transition to more digital twins in manufacturing, many technical advancements have been made. Through the PLENUM project, industry wants to achieve sustainable manufacturing by virtually optimizing design work of production lines. The intention of XR in this case is to create a collaborative virtual reality by the multi-user VR platform [1]. The result of the technology could unlock features which makes collaboration between parties that are in separate places possible for reviewing and manipulating a visual representation of a design review. Also, collaboration is efficiently performed in VR to optimize the task at hand between operators. From a firsthand point of view, VR could provide a significant use to train employees, design workstations, marketing among other things.

Industry 4.0 will bring a higher accuracy for advances in manufacturing. By building virtual models, the design phase could be more precise by getting digital confirmation on decisions. With digital twin and the available visual aid Augmented Reality and Virtual Reality, gives a realistic perspective for engineers to make decisions on work design and operators the availability to train their skills even before getting familiar with the actual real-world operation. These two advanced visualization tools are very functional when it comes to sharing knowledge and getting a feel of the operator's intuition [2]. An exciting potential lies in the ability to digitize the early product development phase. Where areas such as ergonomics, manufacturing, assembly, and maintenance could make use of immersive virtual reality in a design review to offer a more elaborated analysis [3].

Virtual Reality can provide a basis for the end users needs, which in this case for the report would be the assembly station operator. It is crucial for the designer to develop an understanding and empathy for what is necessary for the operator to be able to do the task comfortably. VR has proven to be a reliable tool to understand these needs. Therefore, the contribution that VR brings has a major influence in the designer's work to create a suitable design that ensures quality, safety, and reliability for a process [4].

A company in the vehicle industy want to maximize their use for simulation tools. To do so, the intent would be to find a collaborative way to perform simulations with both VR and the usual simulation depending on what is more appropriate. This would preferably lead to minimizing the grey area where assumption must be made or the designing in the real world, which could lead to expensive changes. Previous studies have shown that companies are interested in these abilities in software. Many suggestions to increase value to the development process was to create a virtual tool for intuitive and visual aid [5]. Furthermore, the need of a multi-user platform was also highlighted for stakeholders to interact in an immersive VR space. Features such as verbal communication and physical presence in form of an avatar deemed to be very relevant to increase the ability to communicate efficiently [5].

Since covid the way of working changed to a more flexible approach where employees are now commonly working from remote locations. This has provided benefits to conduct work despite being face to face with your stakeholders [6]. But in product development it also arises o few challenges with these new working conditions. In design reviews where people go through a product development phase, discussing concerns about design features. Simple tasks such as pointing to specific objects, expressing design change ideas, requesting different viewpoints and ergonomic evaluation in manufacturing processes get neglected and efficiency decreases [7].

Additional participants in the VR space are something people in the industry expect to increase the use cases of the technology when it comes to design review. The accessible platform from a remote location could enable more stakeholders to take part in the deep analysis of the product and therefore unlock a deeper understanding between all parties for further actions. The part of being able interact with people in the immersive virtual reality provided better communication and a better performance in knowledge acquisition [8].

The effectiveness of collaborative VR has been proven in several fields such as the industrial industry. Letting people review projects in a virtual collaborative environment has increased productivity of tasks like building inspection. Engineering is one area where users find immersive multi-user simulation beneficial for addressing issues. Which underlines the usage of this technology in a professional context. With these possibilities the technology has extended itself in to collaborating in areas such as data analysis where the participants can review the same set of data and communicate with each other. The collaborative feature becomes a contributing factor that enhances user experience and provides an effective interaction [9].

In Horvat et al (2022) [10] their study showed that an immersive environment provided less identifications of issues compared to a non-immersive environment contradictory to the information their theory provided. In another study students showed indication of being less effective in an immersive VR space where more distractions occurred and distracted them from the main objectives. Which in this case was to teach the understanding of crystal lattices. The immersive VR was more difficult to use which caused a higher time consumption in navigating the environment and performing the tasks [11].

1.2 Aim

The thesis aims to delve into a transformative potential with the new multi-user VR platform to optimize work design for assembly stations, this contrasting the already existing technology enabled by the IPS software. In the work done, creating a comprehensive framework for the suitability and methodology to use the tool to develop the design meetings process. Strengthening the precision of the simulation is also something the thesis aims to investigate with the new features communication is of essence and increase the versatility of the usage of the platform. Being able to simulate the physical presence of several actors and the prototype design is done to create a sustainable design approach to mitigate travel and reducing carbon footprint. Also, highlighting the significance of fostering an informative feedback loop to deliver valuable input for the existing features and engender novel features for further development of the platform.

Integrating multi-user technology marks a paradigm shift in feasibility of packaging and assembly work aiming to increase quality and efficiency in design and training methodologies. The investigation made in this project is also done to seek clarification in the transition from the traditional ways of working in design meetings compared to the new approach to underpin method selection in use cases. Furthermore, the importance of explaining complexity, collaborative requirements, realism, and cost. The project should enlighten practitioners with an elaborate decision-making framework to assist in their unique context. With different use cases the goal will be to illustrate how different features and possibilities unlock more functions to develop design meetings and how they are done.

By comparing desktop simulation and VR simulation the thesis aim to provide a framework over which methods provide the best output to collect information in an assembly sequence. Through letting people delve in to different methods, data should be collected on how well that method is fulfilling its purpose. The data should be analysed and evaluated to create basis for a framework where methods are distinguished on its advantages and disadvantages. Providing a comprehensive analysis on the data output for future development.

1.3 Delimitations

In the work of the project the main focus would be to analyze the tool used when doing an evaluation appropriate to the design meeting. Therefore, it will not be a priority to delve deeper into an evaluation of certain work designs. Also to take into consideration will be the delivery date of the software since it's predicted to be available week 16 leaves the uncertainty of the timeframe of conducting these experiments. Depending on the time available the test will be designed to cover as many relevant aspects as possible to get a cohesive study and basis for further development. The function list involved in the project is basis for what should be evaluated in the software and the functions that is requested by Zeekr Technology Europe will be the prioritized delivery for the thesis.

1.4 Research Problem

The multi-user platform will give an interactive environment where people can collaborate within the VR space. To do so effectively, the engineers needs to be able to perform certain tasks directly in the firsthand experience. Several functions have therefore been developed to increase the user's ability of what could be done without exiting the VR space. With these new functions, the purpose would be to simplify the simulation and increase the authenticity to replicate a real-world scenario. This project would be to evaluate these functions and the applicability for assembly cases with this multi-user VR platform and evaluate its possibility to perform collaborative and interactive assembly processes.

Research Questions:

- **RQ1**: How is VBE, VIM and DR conducted today and what are the difficulties performing it?
- **RQ2**: How do VR simulation and desktop simulation compare in terms of effectiveness and user engagement during design meetings?
- **RQ3**: Why is VBE 3.0 necessary and what challenges does the multi-user need to resolve?

2

Theory

The following sections are theory related to this project. Where IPS and its functions is explained in context to VR and VBE meetings. This to underline the technical aspects in utilizing IPS to the full extent and reach success in design meetings.

2.1 Virtual Reality (VR)

Virtual reality (VR) is a term going many years back in time, dating back to the 1800s. The technology has evolved a lot since then. What is VR today? In terms of functionality, it's a simulation where computer graphics are used to create a realistic-looking world that responds to the user's input. The computer detects user input and modifies the virtual world in real time. This creates an immersive feeling when being able to see things change in response to their command. The modern VR headsets typically include a stereoscopic display, stereo sound and sensors used for tracking the pose of the user's head. VR is widely used in the gaming industry but is also used for other industrial applications like simulations and operator training. [12]

2.2 Industrial Path Solutions (IPS)

Industrial Path Solutions (IPS) is a math-based software developed by Fraunhofer-Chalmers Centre (FCC) and Fraunhofer Institute for Industrial Mathematics. It's used for automatically verifying assembly feasibility, design flexible components, plan motions, optimize multi-robot stations and simulate crucial surface treatment processes. Functions used in IPS for this project are explained in the sections below.

2.2.1 IPS Path Planner

A tool that can be used for verifying if assemblies can be correctly assembled. It automatically generates a collision free assembly path for an object. It's a strong tool when paired with functions such as shortest distance visualization accumulating coloring along the motions path, showing areas where the operator would have a hard time grabbing objects [13].

2.2.2 IPS Intelligently Moving Manikins (IMMA)

Intelligently Moving Manikins (IMMA) is a tool in IPS that places the operator in focus of simulation, represented by a movable manikin. Its movement is calculated by advanced math, which makes them intelligent, resulting in movements that are always the most ergonomic, always stable, in balance and never colliding with the environment. In IMMA you can create a whole family of manikins with different sizes to be able to represent the whole population with different body types. With this user-friendly tool, the user finds a collation free path for both the object and the humans geometry. In consideration of human diversity, the users are also able to get ergonomic evaluation [14].

2.2.3 VR in IPS

IPS supports VR and enables the user to step into the simulation to see it outside the computer screen and interact with objects. VR combined with IPS IMMA makes it possible to connect a manikin to the VR user which follows the movements of the human. Paired with finger tracking and automatic generated grips, this makes a handy tool for the engineer working in IPS. With the option to record motions with gliding functionalities the VR room does a great job of mirroring reality [15]. Highlighting different parts is important in a complex assembly. It can be done by touching the intended part and therefore also get a visual representation over the active rigid part that now can be manipulated by the controller. Manipulation is done by pressing the trigger button which attaches the object with the controller and follows its motion. Release is done by letting go of the trigger button and then the object gets placed wherever that action is done.

Movement in the VR space can be done in several ways.

- Teleporting
- Stepping backwards
- Turning
- Smooth Locomotion
- Raise/lower floor

By pressing the trackpad button or moving the joystick upwards a beam lights up when teleporting. With this the operator can aim that beam wherever they want to go and by releasing the button this action will take place. Stepping backwards is done by pressing the trackpad button or moving the joystick to a southern direction. This is enabled when the Locomotion VR setting are put to teleporting. Turning the view is done in discrete increments by pressing the trackpad button or turning the joystick left or right and are disabled when the locomotion is set to none. Smooth Locomotion can be done by moving the joystick up or down and is enabled when the Locomotion setting are set to smooth. This gives the operator the ability to glide along the floor in the direction pointed. The floor height can be adjusted when entering *move floor* mode. This is not bound by any controller but enabled in the SteamVR settings [16].

2.2.4 VR Equipment

The user puts on a head-mounted display (HMD) that's affixed to the head. The HMD comes with displays as sources for the images viewed in VR. Also includes inertial measurement units (IMUs) to track the user's motions with the head, enabling 6-DoF. To be able to represent a real-world scenario, there also needs to be something tracking the hands of the user, the handheld controllers. The controllers are tracked and visualized in the 3D space, in IPS the representation is 2 hands to further actualize the simulation. The available controllers for this project have finger tracking that's based on built-in sensors. Finger tracking enables more natural motions when interacting with objects. [17]

2.3 Assembly line in car manufacturing

Companies today are facing challenges such as rapidly changing customer needs and market dynamics, necessitating shorter product launch times while maintaining quality. Industry 4.0 emphasizes smart production and products, leading to the need for quicker rebuilding of production lines. To address these challenges, companies are turning to simulation software to optimize engineering activities, shorten production line building time and reduce the time needed for building prototypes. Simulation enables verification of production and product before implementing the proposed changes, thereby preventing errors in a early stage. The further in in the development phase that the error is discovered, the more significant the challenges become when trying to address it, increasing cost and time spent. By using simulation, companies can increase overall production effectiveness and competitiveness. It also enables testing proposed measures before implementation to prevent errors and gain a better understanding of production processes for proposing changes effectively [18].

2.4 Student's t-test

To understand significance in a small sample from a large population it is possible to use a method called the Student's t-test [19]. This is an equation that compare the result of two samples after a experiment is performed on them. This test is the most effective if the assumption is made that data is normally distributed and samples is assured to be correct. If there is no difference in the test result, then the null hypothesis is determined to be true. The null hypothesis would be that there is no major difference between the two conditions. If the difference is significant, then a contradictory hypothesis, that it is a major difference between the two conditions. The two data sets can be compared with the equation:

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} \tag{2.4}$$

Where:

- $\bar{X}_1$ and $\bar{X}_2$ are the sample means,
- s_1^2 and s_2^2 are the sample variances,
- n_1 and n_2 are the sample sizes.

2.5 Difficulties with non-immersive communication

Being able to use gestures in form of hands, finger, head, face is a ability that further enrich communication providing additional information to the verbal communication. Studies on remote non-immersive online meetings that have been made indicates a lower rate of creative ideas as well as total ideas compared to meeting generated in a face to face environment [20]. Reason for this was that participants feared the possibilities of being evaluated, social facilitation, social loafing, social sensitivity to name a few reasons [20]. When the participants of the meeting don't have the ability to encounter the people in person, social cues was determined to be abstract and non existing. Therefor people struggled with these aspects when they could not read people body language as well as provide such communication themselves [21]. Due to the use online communication tools, difficulties with technology occured and people experienced frustration with poor camera usages and microphone difficulties with annoying background noises [22]. Studies have also showed that engineering students who interacted in a immersive meeting setting felt a higher social presence and performed better in a immersive setting when the tasks at hand were education, training and meetings [23].

2.6 Evolution of Virtual Build Event (VBE)

2.6.1 VBE 1.0

The VBE meetings have evolved over the years and will probably continue to do so with the evolution of new technologies. But the initial version of these meetings, VBE 1.0, where not very efficient in terms of technologies utilized. With the use of Microsoft Teams, the host shared screen and displayed CAD designs on Teamcenter. The engineers show their parts and explain with words how they plan to assemble parts, while the rest of the participants must imaginate the path of objects and tools.

2.6.2 VBE 2.0

VBE 2.0 is the current way Zeekr Technology Europe work on these meetings. To tackle the difficulties with VBE 1.0, were participants must imagine the paths of objects, a new software was implemented, IPS. With IPS and the tools within it, it's possible to plan paths for objects to show how parts are assembled. They can even add tools and show accessibility with IMMA, grip- and viewpoints. VR was also implemented that allows the host to enter the simulation and get a first-person view of the assembly, it can for example help with detecting hidden assemblies.

2.6.3 VBE 3.0

VBE 3.0 are the next generation of how these design meetings could be conducted. One way of aschiveing this VBE 3.0 is to introduce the multi-user platform with integrated VR. This enables participants to collaborate in a whole new way, promoting a more immersive and interactive experience. With the integration of multi-user VR, participants can join the meeting from different locations and interact with each other and the virtual environment simultaneously. This not only enhances communication and collaboration but also allows for real-time decision-making and problem-solving. VBE 3.0 represents a significant advancement in design meeting methodologies, leveraging cutting-edge technologies to facilitate collaboration, innovation and decision-making in the product development process. These advancements is determined to be enabled by the XR technologies, and the extension of the collaborative tools developed through this project.

3

Methods

The methodology for this project is theory mixed with practical work, following the structure of design research methodology (DRM).

3.1 Design research methodology (DRM)

Design Research Methodology (DRM) is a structured approach used in this research. It outlines various stages and concepts aimed at achieving two overarching objectives: formulating and validating models and theories about design phenomena, developing and validating knowledge, methods, and tools to improve design outcomes. DRM consists of four stages: Research Clarification, Descriptive Study 1, Prescriptive Study and Descriptive Study 2. DRM framework is presented in figure 3.1. [24]

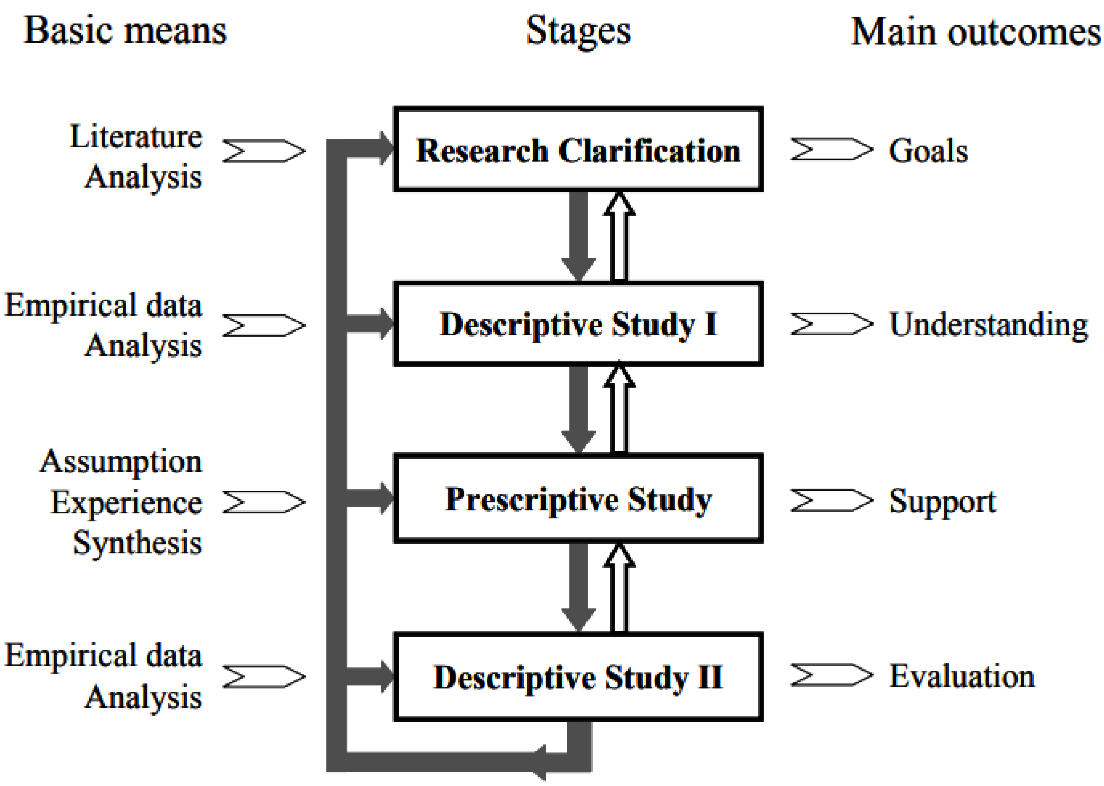


Figure 3.1: DRM framework

The stages of DRM: represented by downward arrows indicating natural progression. Upward arrows signify potential iterations between stages, while horizontal arrows denote the methods used within stages and the outcomes achieved.

Table 3.1: Research questions answered by the report

	Research clarification	Descriptive study - I	Prescriptive study	Descriptive study - II
Report	Review	Comprehensive	Initial	

The majority of methods used for this project was qualitative studies. Ere interviews, observations, field visits, interactive focus groups, and discourse analysis of virtual built event at Zeekr Technology Europe.

3.2 Research clarification

In the Research Clarification (RC) stage, researchers seek evidence or indications to support their assumptions to enable the creation of a realistic research question, primarily by reviewing literature on factors influencing task clarification and product success. They develop initial descriptions of both the current and desired situations, making underlying assumptions explicit. [24]

The identification of relevant literature related to the topic will be conducted through using a method called backward snowballing. The first step is to identify a set of papers and evaluate them. These papers will be identified through an online search using well established databases such as the Chalmers Library Database, Google Scholar, Scopus and ResearchGate. The search will be limited by several factors: year of publication, 2019-2024, for more relevant theory with modern technology, and the vehicle industry. Combinations of keywords relating to one or several of these subjects will be applied. Keywords such as: Virtual Reality, VR, Multi-User Platform, Manufacturing and Design Review.

When a set of useful papers has been identified, the papers will enter the snowballing procedure. Firstly, the identification of the titles will be done to see where they have been used in the paper. If it's not useful the next reference will be evaluated. If it could be useful, then that paper will be reviewed. First the abstract of the paper referenced, then the full paper if appropriate. This procedure is iterative and performed until no new papers are found. The result will be a complete list of several suitable papers [25]. The literature found will be the foundation of the report and the background for research question 1.

3.3 Qualitative Study

During the Descriptive Study I (DS-I) stage, researchers refine their understanding by reviewing literature and observing designers at work. They aim to identify factors crucial for improving task clarification. Despite insufficient evidence in literature, they proceed with observations and interviews, revealing issues with problem definition. Logical reasoning guides their decision to advance to the Prescriptive Study stage. [24]

For this project, DS-1 stage includes a qualitative study phase that consists of interviews with stakeholders for the project and employees at Zeekr Technology Europe. The objectives here would be for them to provide insight for the experiments, help with understanding VBE, DR and VIM, old way of working and current way, but also their expectations for VBE 3.0. Their insight within VR and multi-user platforms varies but is clarified by questions regarding their experience.

The semi-structured interviews followed a list of core questions [A] regarding their experience of VR and multi-user platforms, what functions they believe are necessary and unnecessary. Their current knowledge of VBE, DR and VIM, also, what they would like to see in the future for these meetings. The interviewers will be prepared to be flexible in terms of the order in which the topics are discussed and to let the interviewee develop ideas and speak more widely on the questions asked. This is to create more open-ended answers filled with their own ideas. The goal for the interviews is, as discussed, to help with the experiments' design and provide valuable insights needed to give well-nuanced answers to the research questions. Guidelines for the design of the qualitative study were collected from [26] chapter 10. All interviews were transcribed to document the result provide evidence for claims made. Table 3.2 shows the interviewees reference numbers in the report, what design meeting they work with and what department they are from.

Table 3.2: Interviewees

Ref. Nr.	Design meeting	Department/role
[1]	VBE	Packaging, TFC & Concept Dev.
[2]	VBE	Packaging, TFC & Concept Dev.
[3]	VIM	Packaging, TFC & Concept Dev.
[4]	VIM	Packaging, TFC & Concept Dev.
[5]	DR	HV Battery & Thermal Systems
[6]	DR	HV Battery & Thermal Systems
[7]	DR	Chassis & Electric Drive

3.4 Empirical Study

In the Prescriptive Study (PS) stage, researchers refine their vision of the desired situation based on their understanding. They focus on improving problem definition to reduce modifications and shorten design time. Using a design methodology, they develop a software tool to support problem definition. Initial evaluation shows correct development, but the tool's effectiveness remains unclear due to underlying assumptions. [24]

3.4.1 IPS Training

The pre-assumptions of the project made an initial understanding that familiarization is of order to be able to do a comprehensive study on the subject. Therefor experience in the software is of the essence to conduct the tests and analyze the result. To achieve this experience, a training program of IPS is undertaken to get a practical understanding of the software's interfaces and operations. Simultaneously empirical testing is done to scrutinize certain features relevant for the project such as IMMA and path planning. This should also be made sure to seamlessly be integrated with the VR features to extend the simulation for design purposes in a virtual environment.

Furthermore, the exploration phase involves the identification of functionalities within IPS, to incorporate in the project if they align with the objectives for this study. For testing collaborative multi-user function, validation should be done by testing an old version of multi-user IPS. This is to ensure the server reliability and connection settings for multiple IP addresses. Throughout this iterative process the aim would be to set standards in a protocol for a further purpose to evaluate the empirical study conducted afterwards on the newly released software. This is to ensure the ability of the software relevance to the industry and design meeting overall.

3.4.2 Design of use case

Previous studies focused on finding challenges with the daily work being conducted and what tools could be useful in future software. The objective for the demo would then be to use these obstacles and input to design experiments in IPS. The simulation set-up considers real scenarios where the participants get to try out VBE where they have access to the new functions with the multi-user platform. To design a good experiment, an iterative process will be conducted with testing in IPS for both single-user and multi-user applicability. The scenarios are made to add clarification to certain use cases where the participants use the tool and its new functionality to make an analysis over the situation.

To generate a broad result and enable testing of several functions, 3 different scenarios will be created, see figure 3.2.

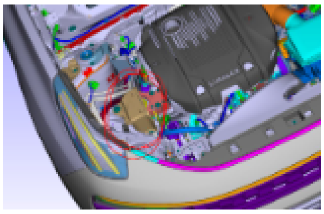
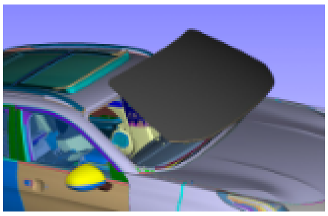
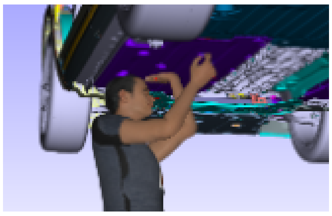
Scenario	Figure	Description
Engine damper		Is it possible to assemble the engine damper without scraching the engine cover? Participants will evaluate and test the assembly in VR and from desktop, make a path planner if necessary.
Front window		It's hard to assemble the front windscreen. Requires 2 operators trying to guide the windscreen in right place. The participants will have 2 in VR collaborating and try to assemble.
Plastic cover		Evaluate the assembly of plastic cover underneath the car at 180cm hight. Operator uses one hand to lift the cover, and the oether hand to enter screws. Participants will evaluate the assembly and egonomics.

Figure 3.2: Three Scenarios for multi-user demo, *Source: Screenshot from IPS, "Lynk & Co 01".*

The scenarios are chosen together with interviewee 1 and 2 [Table 3.2]. Each scenario are something that has previously been a problem and discussed during design meetings. This is to create a setting as close to reality as possible and to be able to compare if the new available tools are more useful.

Hypothesis for the demo: Enables multi-user collaboration and increases communication effectiveness during design meetings.

3.4.2.1 Scenario 1, Engine damper

Scenario 1 is the assembly of the engine damper, see figure 3.3. The engine damper is located to the side of the engine and is held by 6 bolts. The challenging part of the assembly is that there is very limited space. It's hard for the operator to place it without scratching it against other surfaces. This scenario is interesting because when doing simulations with path planner on the desktop the sequence looks very possible without trouble. However, in reality it's a very challenging assembly to get right without making contact with other parts. The scenario involves testing the assembly, in VR and with path planning on desktop, then discussing the problem and solutions.

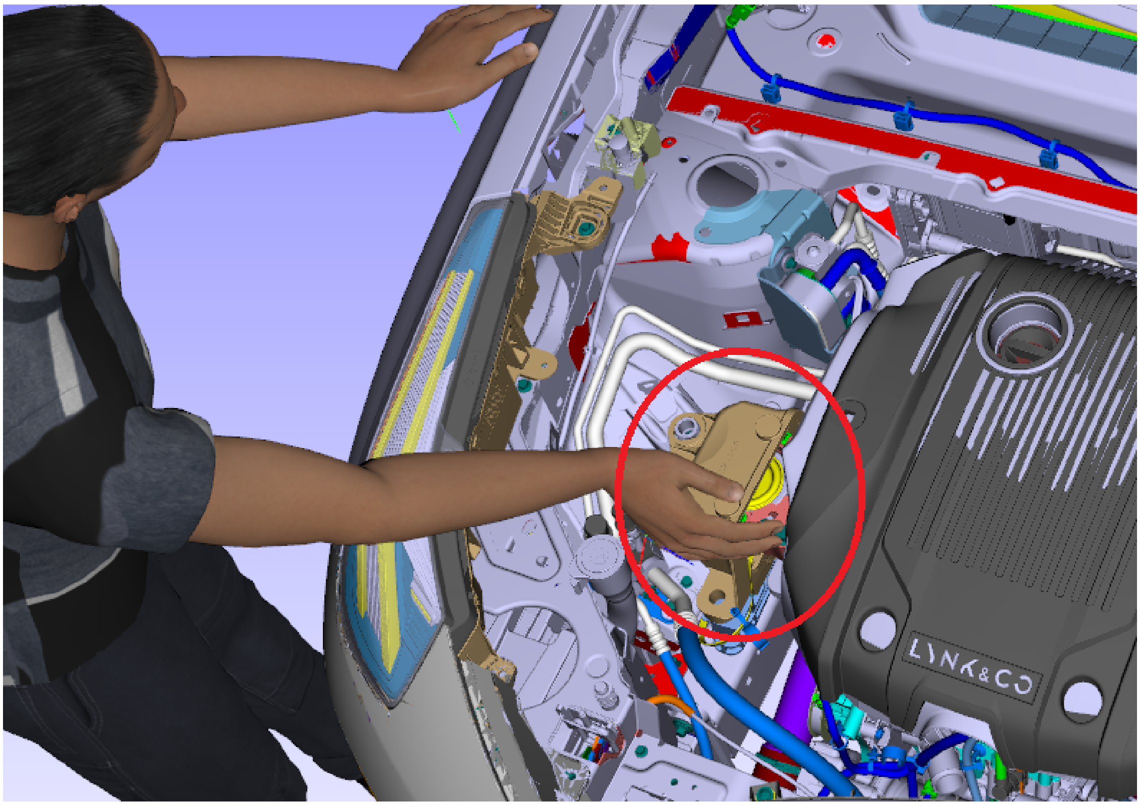


Figure 3.3: Assembly of the engine damper, *Source: Screenshot from IPS, "Lynk & Co 01".*

3.4.2.2 Scenario 2, Front window

Scenario 2 is the assembly of the front windscreen. The window is assembled by 2 operators collaborating by standing on opposite sides of the car and placing the window with the help of suction cups, see figure 3.4. The hard part of the assembly is that there are guide pins on each side that needs to align, see figure 3.5. This scenario is interesting because 2 operators need to co-operate in order for the windscreen to be assembled in a correct way.

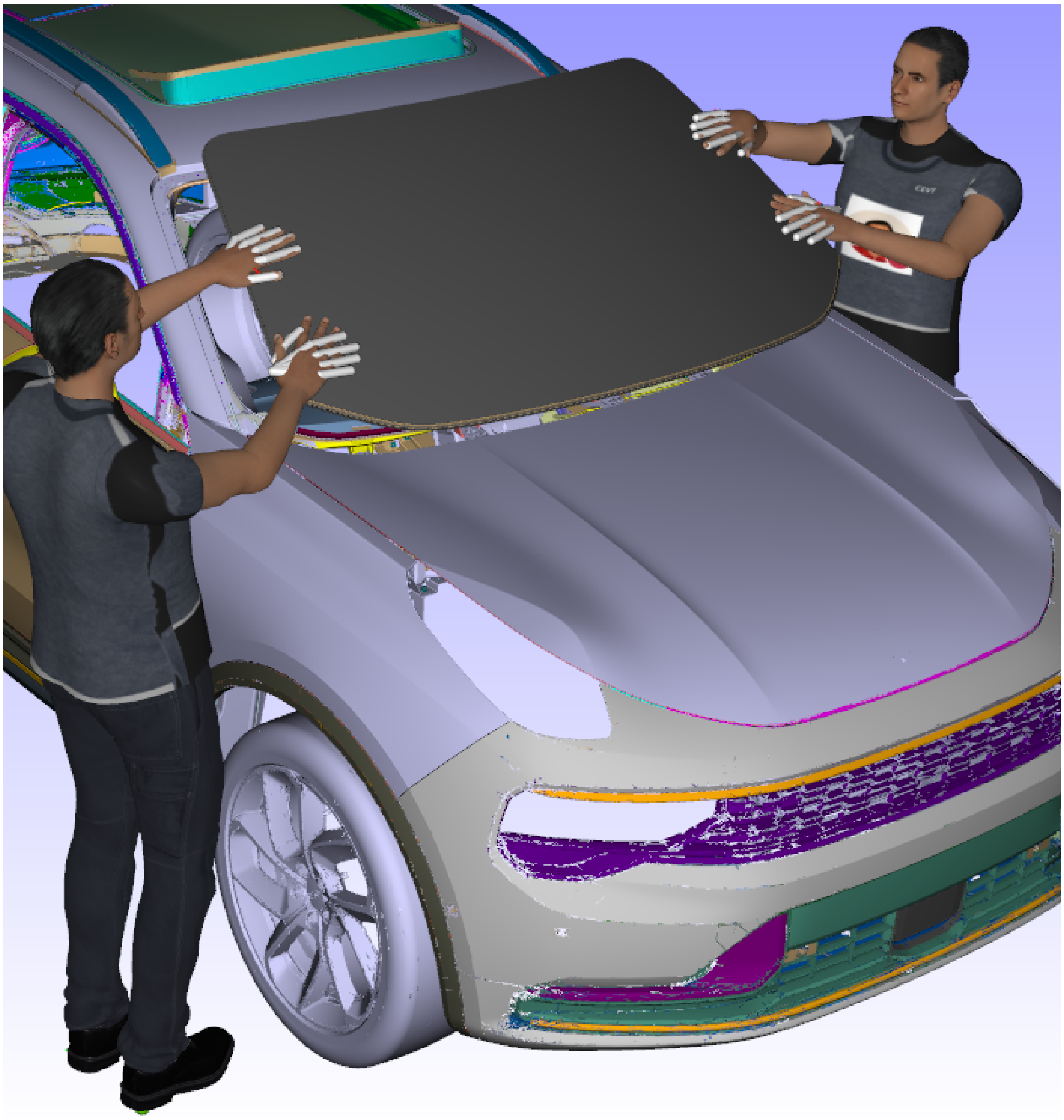


Figure 3.4: 2 operators collaborating on assembly of the windscreen, *Source: Screenshot from IPS, "Lynk & Co 01".*

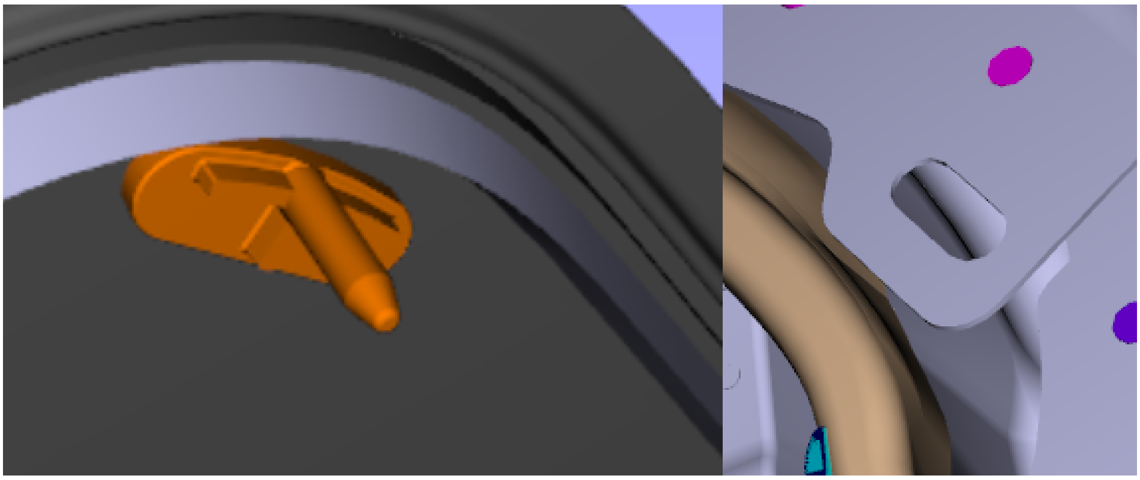


Figure 3.5: Pin on the windscreen (left) and hole in the frame (right), *Source: Screenshot from IPS, "Lynk & Co 01".*

3.4.2.3 Scenario 3, Plastic cover

Scenario 3 is the assembly of an plastic cover underneath the car. An operator is holding up the plate with one hand and entering several screws with the other hand. This is a hard assembly due to the position and height of the vehicle. The operator needs to stand under the car and do the assembly at 180cm from the ground. This causes ergonomic issues depending on the height of the operator. For the demo, the engineers will evaluate the assembly from the perspective of a person being 150cm, 175cm and 200cm to see how the different heights affect the worker.

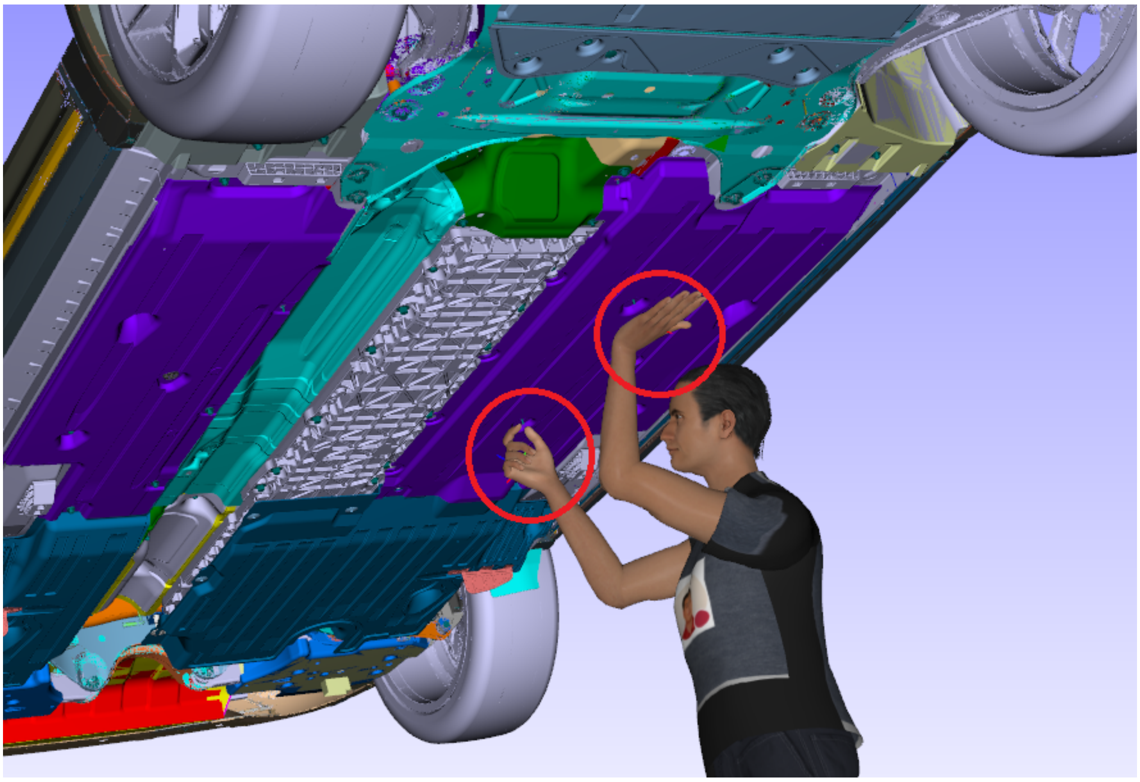


Figure 3.6: Operator assembling the plate, *Source: Screenshot from IPS, "Lynk & Co 01".*

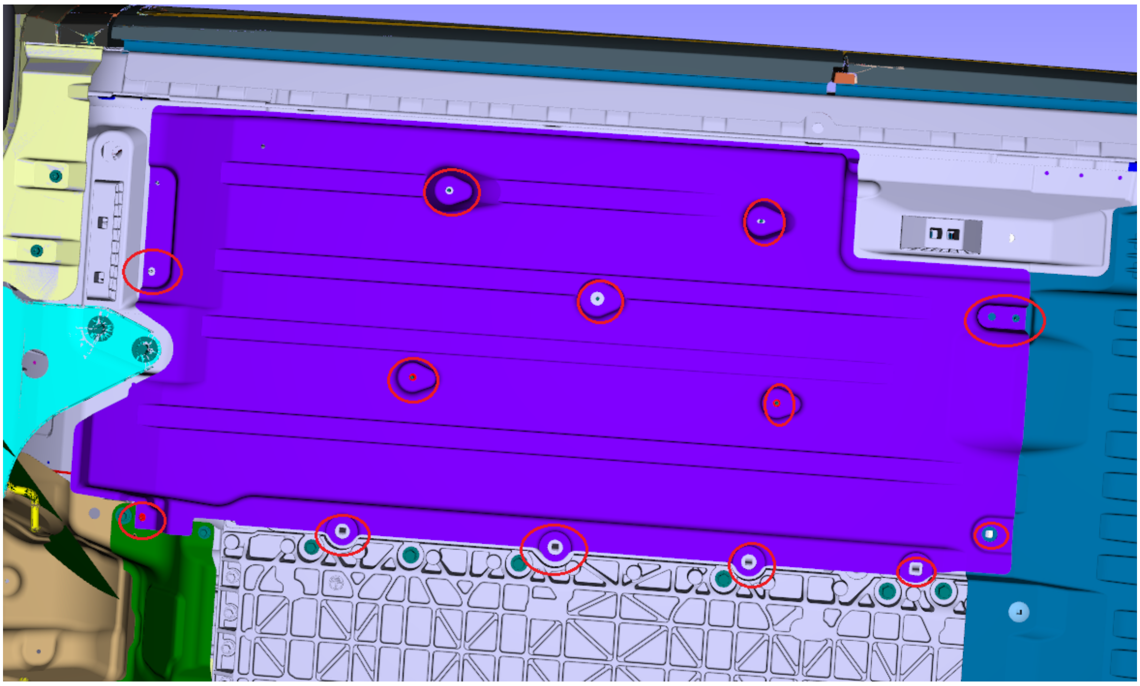


Figure 3.7: Places where screws are entered, *Source: Screenshot from IPS, "Lynk & Co 01".*

3.5 Single-user investigation

Due to uncertainty of the delivery of the multi-user platform a test on the single-user platform will be conducted. In order to get a relevant result on this platform, the objectives will be aimed towards the initial state of the PLENUM project. Were information about current available methods will be evaluated as well as what they are lacking in order to reach their full potential.

3.5.1 Design of single-user investigation

There will be 2 workshops with 4 participants each where all 4 people test out different roles during the session. The different roles for the testing are designers and observers. The researchers act as meeting host and secretary. Participant 1-4 in the first workshop and participant 5-8 in the second workshop, table 3.3. There is a gap in the knowledge and experience of the participants.

Table 3.3: Participants and their experience levels

Participant	Experience
1	VBE, IPS, VR, vehicle industry
2	VBE, IPS, VR, vehicle industry
3	IPS, VR
4	VR
5	Vehicle industry
6	Vehicle industry
7	IPS, VR, vehicle industry
8	IPS, VR, vehicle industry

Before the test, 3 use cases will be prepared with a complete realistic simulation. The goal is to evaluate the different scenarios and collect interesting data that was raised during the interviews. The data that should be collected and analysed during the workshops.

Each person should first wear the VR headset to try out the assembly sequence and navigate procedure in the best suited way for that person. In the next step, the desktop simulation is shown and everyone observe the simulation to compare the result with their own experience in VR to see if the same output of data could be retrieved. The participants will be asked to think and reflect about the following:

1. Do you fully understand the assembly?
2. Do you understand the challenges with the assembly?
3. How does it feel in you body when doing the assembly?
4. Is it hard/exhausting to do the assembly?
5. Do you see where the parts are placed on the car?
6. Will you have easy tool access for fastening screws?

3.5.2 Evaluation of single-user investigation

To evaluate this workshop, one researcher will observe the entire session and document everything that happens. By engaging in these different types of simulations, the effectiveness and clarity of the information received is evaluated in a survey, to see if the objectives are affected by the difference of immersive vs non immersive simulations.

To collect data from the testings, methods for analyzing user experience will be used. Its two different methods that is determined useful in this case. During the experiment data considering the cognitive demand will be collected through the use of nasa tlx. This score will be compared between the desktop simulation and the immersive VR simulation. By evaluating the cognitive load of the different work methods, one could evaluate the more appropriate method for certain tasks. The analysis is determined to provide insight in the effort needed to complete the task and therefor resulting in an indication on whether that certain method is suited for the design meeting. Additionally a survey will be handed out after the test which in a form of the Likert scale. The statements will be collected from the interviews considering the major contribution relevant for a VBE. Which are the assembly feasibility. The participants will include both experts in the field and people with little to non experience using IPS nor VR tools.

To further analyse the result from the survey, a T-test will be preformed on each question. A T-test helps in determining whether the differences in the survey responses between two groups (participants using VR versus those using desktop simulations) are statistically significant. The T-test is effective even with small sample sizes, making it a practical choice for survey data analysis where the number of participants are limited. This will help in determine which questions to focus on, where the experiences from VR and desktop simulation deviates the most. Also to discover if the hypothesis for the study is true or not.

Hypothesis formulation:

- **Null hypothesis:** There are no difference in the amount of information the participant of design meetings gain when using VR instead of desktop simulation.
- **Contradictory hypothesis:** There are a significant difference in the amount of information the participant of design meetings gain when using VR instead of desktop simulation.

3.5.3 Design of Multi-User platform evaluation

This study is centered on the evaluation of a Multi-User platform through testing. The evaluation process will involve going through a protocol, which has been compiled for this purpose. Each function of the platform will be assessed by answering whether it meets the criteria outlined in the protocol (OK) or not (NOK). The protocol itself draws from multiple sources, including pre-study interviews, insights gathered from the PLENUM project, and feedback from software developers. These sources provide valuable input regarding the desired features and functionalities of a multiuser VR platform. The evaluation will involve testing and assessing each function listed in the protocol. The goal is to determine the practicality, usefulness, and performance of the platform's features. Through this systematic evaluation process, insights will be gained into the platform's strengths and areas for improvement.

3.5.4 Design of multi-user demo

The participants in the tests will be senior engineers with experience in both product design and design meetings. All the participants are part of the vehicle integration department and will be called to the tests in groups of 3 at a time. They are given a short description of the scenario, what the problem is about and what to evaluate. Then they will be given a framework for how to use the available tools in the simulation. The participants do the VBE for the current scenario, followed with a discussion together with the researchers where they evaluate how the problem was solved using the tools. Participant 1 and 2 will be inside VR preforming the assembly and participant 3 will join from desktop. The roles for desktop and VR will rotate for each scenario so everyone gets to try VR. Researcher 1 will assist in the demo, while researcher 2 will take notes.

When all 3 scenarios is done there will be an open discussion regarding the tools effectiveness. The questions to discuss after demo:

- Was the tasks solved in a correct way utilizing the multi-user platform?
- Are there any limitations due to software issues?
- Does the multi-user platform increase the overall efficiency of the problem-solving?
- Are there any functions missing that would be useful in these scenarios?

3.5.5 Evaluation of multi-user platform

Transitioning to the Descriptive Study II (DS-II) stage, after the empirical studies, to assess the tool's impact. To evaluate its applicability and usefulness, focusing on reducing modification time and time-to-market [24].

The DS-II consists of qualitative and quantitative study and is designed to collect information used as data later in the analysis. It contains a written list of questions; each participant received an identical set of questions which gives consistency and precision and allows processing of the answers easier. The methodology adopted for the quantitative study involves gathering relevant data about the impact of VBE 3.0. This will be possible by administering an online survey to the participants. Guidelines for the design of the qualitative study are collected from [26] chapter 9. For the qualitative part, another semi-structured interview was held again with the participants after the experiments to further discuss their experience.

If the multi-user are not delivered, the initial step of providing a function list of requirements from industry will be the most interesting part. This will provide information of necessary steps that has to be taken in the development phase to provide a competitive platform.

4

Results

In this chapter the major findings considering the research questions will be presented. The research involved a literature study, a qualitative study, and an empirical study described in the previous chapter. The research questions are targeting the potential a multi user platform would have in design work. Furthermore, a comparison between VR simulation and desktop simulation is evaluated through a workshop.

The literature study and qualitative study have their major contribution to answering **RQ1**; How is VBE, VIM and DR conducted today and what are the difficulties performing it? The empirical study with support from qualitative study gave result to answer**RQ2**; How do VR simulation and desktop simulation compare in terms of effectiveness and user engagement during design meetings? For **RQ3**; Why is VBE 3.0 necessary and what challenges does the multi-user need to resolve?

Research Question	Literature Study	Empirical Study	Qualitative Study
RQ1	x		x
RQ2		x	x
RQ3		x	x

Table 4.1: RQs answered

4.1 Qualitative study

4.1.1 How are the design meetings conducted today

Vehicle Integration Meetings (VIM) are structured around addressing issues and solutions related to different areas of the car, such as front, rear and interior of a car. Each area is managed by different team members responsible for that specific module. The meetings involve interactions with various stakeholders, including team members, suppliers and other relevant parties. Collaboration is facilitated via tools like Teams. Issues are logged and tracked using a severity rating system, with severe issues given higher priority on a scale 1-5, 5 being the highest rating (highest priority) and 1 being the lowest rating (lowest priority). Discussions focus on proposing solutions, which may involve simulations, evaluations or adjustments to the design. [Interviewee 3 and 4, table 3.2]

Virtual Build Event (VBE) serves as a collaborative platform for engineers to discuss assembly designs, ensure cross-functional alignment, and validate design decisions through interactive evaluations and assessments. The primary objective of a VBE is to facilitate collaboration and decision-making among engineers involved in the assembly design process. By bringing together experts from different departments, such as System Project Leader, simulation and manufacturing engineers, the VBE ensures that all perspectives are considered, and potential issues are addressed early in the design phase. The first 3 weeks are for preparing input, deciding on what to include in the VBE, preparing the 3D data and documentation. The following week there is 1 week for creating the IPS base scene. Simulation execution is 3 weeks and it's the part where most of the VBE work is done. The engineers process the model and examine if assemblies are feasible with path planning and manikins. Lastly there is 1 week allocated for Analyzing results, the big meeting. A typical VBE meeting spans approximately 3 days, allowing sufficient time for thorough discussions, presentations, and evaluations of assembly designs. This extended duration enables participants to delve deeply into the details of each component and ensure comprehensive review and analysis. [interviewee 1 and 2, table 3.2]

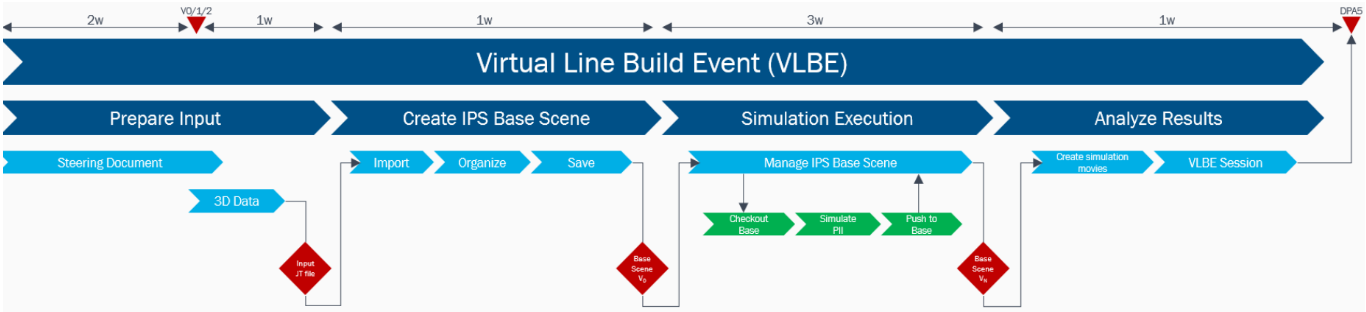


Figure 4.1: Typical process of VBE. *Source: Collected from Zeekr Technology EU NPDS.*

During the VBE, participants join the meeting dynamically based on the focus of discussion. When a particular component or assembly is under review, relevant engineers "jump into" the meeting to provide insights, share expertise, and contribute to the decision-making process. The VBE involves interactive presentations where parts are visually showcased, participants can view the screen and see what the moderator sees. Throughout the VBE, participants assess the assembly designs based on predetermined criteria, including:

- Assembly sequence: The order in which components are assembled to form the final product.
- Assembly path: The physical trajectory or route followed during the assembly process.
- Tool access: Accessibility of tools and equipment required for assembly tasks.
- Ergonomic assessment: Evaluation of assembly processes in terms of ergonomic considerations to ensure worker safety and comfort.

Initially, there were large **design review** (DR) meetings where each team presented their progress. However, the process has changed and now meetings are more focused on one-on-one discussions, primarily conducted through digital platforms, according to interviewee [5], [6] and [7], table 3.2. Collaboration with suppliers is crucial, especially in the early stages of product development. Suppliers provide valuable feedback on design feasibility and potential manufacturing issues. While most discussions are based on data and documents, there's recognition of the potential benefits of visual communication, especially when collaborating with international suppliers. Virtual reality tools could enhance understanding and facilitate communication in such scenarios, but the occasions are few. The communication during DR is asynchronous. The engineers work with their own product and send over their CAD files to others if needed. The DR meetings is used to go over the overall progress of the work. Mostly verbal, without visual aids.

4.1.2 Challenges with design meetings today

According to interviewee 1 one problem related to VBE is that during these events people from China is connected through teams from the factory to give their feedback. They are limited in their view by only seeing the IPS window and the VR-view and are not able to manipulate anything. For a better analysis from China they should be able to enter VR and manipulate objects.

With many issues to address and stakeholders involved, there's a need to ensure that meetings are efficient and focused. Time management becomes crucial to avoid prolonging discussions without reaching satisfactory solutions. Therefore, ensuring effective communication and collaboration among team members, especially when dealing with cross-functional issues is crucial according to interviewee [4], but it can be difficult. It's important for all stakeholders to be on the same page and understand the implications of decisions made during the meetings. Visualizing design proposals and understanding their implications, especially in terms of spatial constraints, thermal considerations, and serviceability, can be challenging. Without proper visualization tools or VR support, it may be hard to grasp the full extent of certain design decisions. Interviewee [4] also mentioned his interest in measuring time with the multiuser VR platform. Primarily when it came to serviceability and disassembly to increase the understanding of accessibility to certain parts of the design. If this could be done efficiently a deeper knowledge could be acquired from a vehicle integration perspective. Since the connection between China and Gothenburg is very good internet tools should be more integrated in the communication. According to interviewee 4 its challenging right now in communication due to the understanding of each other. When the Swedish team speak in meetings the China department does not listen and when the Chinese department communicate the Swedish team does not listen. With a collaborative platform these agenda could be explained together in the VR space to make the points clearer.

"So when we'll be talking, they will not be listening. And when they talk,

we will not listen. But since we have good network connections and stuff, we should collaborate in VR. So it's better to it's better in to explain them in a way instead of just showing the tag you join in the VR. I joined in the VR I present to you what I mean."
Source: Interviewee [4], table 3.2

Interviewee [3] explains that there are challenges during VIM when navigating virtual environments or interpreting visual representations of design elements. In the CAD, parts look easily reachable without collation, but when turning the screen in another angle or zooming out, it's clear that it isn't the case. It can also be hard to see the real scale of objects when just looking at a 2D-screen explains interviewee [3]. One reoccurring problem that the participants mention is that it's sometimes hard to see in simulation programs if it's a hidden assembly, i.e. if you can see the bolt you are about to tighten. There are also other concerns when planning for the assembly, when you don't know how tall the operator is. A tall person might not experience the same forces and strains to the body as a short person.

Figure 4.2 below shows the difficulties performing the design meetings today. The arrows from VBE and VIM indicate if they have experienced this challenge.

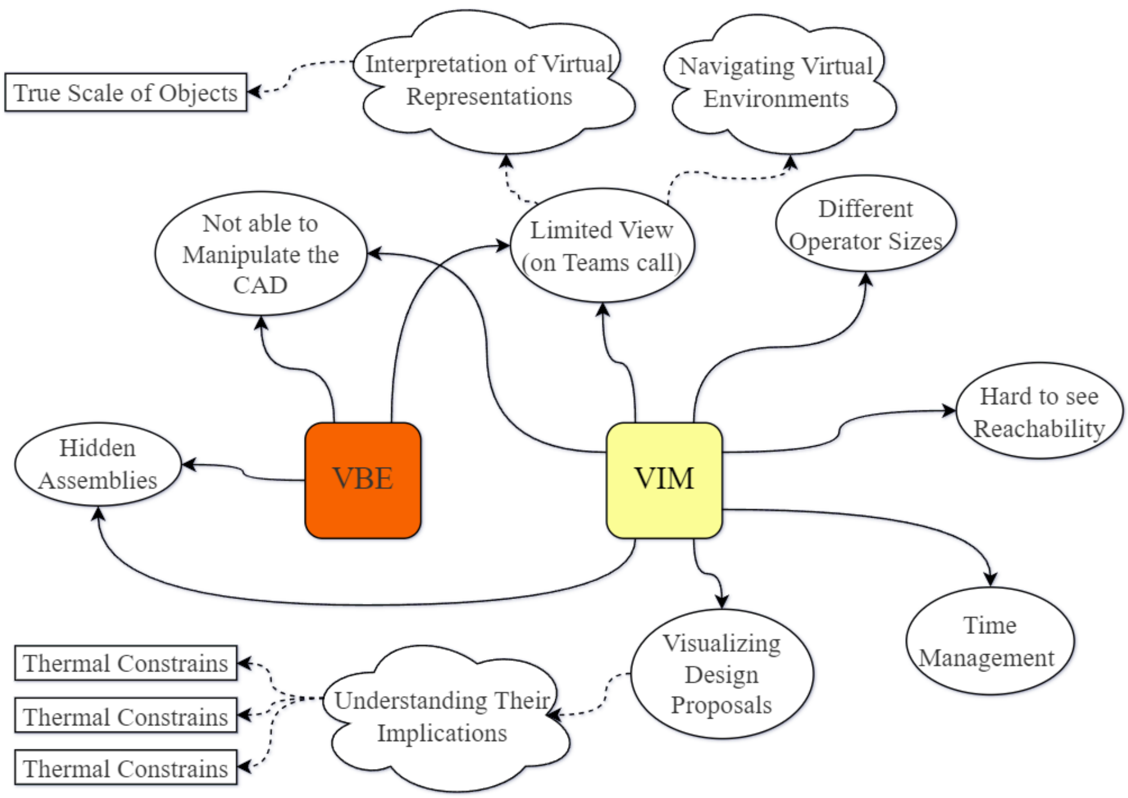


Figure 4.2: Summary of challenges identified during interviews. *Source: Interviews conducted by the research team.*

It's important to know that VBE and VIM don't utilize the same simulation tools today, hence there are some challenges experienced during VIM that could be solved by using other tools like IPS. Examples of those are **"operator size"** and **"reachability"**. Operator size means that they experience that it's sometimes hard to tell if a tall and short person would have trouble with an assembly. **"Time management"** is also an issue during VIM meetings according to interviewee [4]. It implies that it might be hard to focus on the right stuff during the meetings. **"Visualizing design proposals"** relates to the challenge to understand the implication of design changes. For example, how moving an exhaust pipe would impact the space for other components or if the high temperature from it would melt other plastic parts adjacent to it.

The struggle with **"hidden assemblies"** is something they both experience. It's a common problem when working with CAD where it's hard to determine if the assembly is feasible for the operator due to other parts being in the way. **"Not able to manipulate"** refers to that the participants can only watch the screen being shared with them. They can't add objects or change the CAD; instead, they must explain to the rest of the meeting what they want to change. Similar to that challenge, is **"Limited view"**. Everyone in the meetings sees the same screen and can't change the camera angle in the way they want it. This leads to complications when trying to interpret the CAD and understanding the scale of objects. Discussion with product owners creates dilemmas where understanding problems were two different stakeholders have a different view on the same matter.

4.1.3 Needs and wishes for multi-user

For a new car to be developed, several issues tend to arise in the beginning of production. During the development phase, production lines are optimized, and communication needs to be efficient in assistance to the operator in order to understand the sequence of assemble when getting new instructions [interviewee 3]. Having direct contact with people in production across continents is helpful when explaining new procedures for new products. For the operator to meet with the engineer in a virtual space to explain exactly how parts should be assembled makes the process even more efficient instead of them figuring it out themselves or reading difficult instructions. In those moment changes can be made in real time if necessary interviewee [3]. Several interviewees expressed their willingness to collaborate more closely to their Chinese production plant colleagues since that is not done at a high rate at the moment. This indication of collaboration would correlate more with training in VR but as mentioned crucial issues in design could also be encountered at this stage.

The information collected from the interviews was the basis for further testing and provided necessary input to creating a table with needs and wishes on the multi-user platform, table 4.2. In order for the multi-user to be successful, it needs to work as an efficient communication tool, creating direct contact with global colleagues. It needs to have an user-friendly appearance with recognizable functions and build in buttons for easier handling and all participants must be able to manipulate the CAD to increase overall understanding of each other to visualize design change proposals.

Table 4.2: Needs and wishes

Needs	Wishes
Direct contact with global production colleagues for efficient communication and collaboration across continents	Collaborative training in VR to enhance skills and knowledge sharing
The program and computer needs to be able to handle large files, without disturbances reducing the feeling of immersion	Fast and convenient connection to the server and simulation file
Comprehensive visualization tools for understanding design proposals and their implications	Accessible for participants not integrated with the IPS platform
User-friendly design for users with varying levels of prior knowladge in IPS and VR	Efficient communication tools for understanding assembly sequences and making real-time adjustments during assembly
All participants are able to manipulare the simulation/CAD	

To further clarify the demands on the new software, the needs and wishes was transformed into two function lists. One list for the user friendliness of the procedure to use the tools in an efficient way, table 4.3. Along with a different list that includes more software functions in IPS and VR space, table 4.4.

Many members of the vehicle integration team are not accustomed to utilizing IPS in their daily tasks, underscoring the importance of user-friendliness in any new simulation program. It must have an intuitive interface and seamless navigation, mirroring the layout and functionality of other CAD software. This familiarity is crucial for enabling users with limited prior experience with IPS to quickly adapt and utilize the program effectively. Additionally, the process of launching the simulation, accessing the appropriate CAD files and connecting to the server should be straightforward and hassle-free. Converting models to the requisite format and setting up VR scenarios present significant challenges. The effort required for such tasks may outweigh the potential benefits, particularly if the VR showcase pertains to smaller-scale projects. Thus, simplifying the file conversion process and streamlining VR setup procedures are important. Minimizing the time spent on these tasks is essential to enhance overall efficiency and usability.

Table 4.3: User-friendly requirements

PRINCIPLES	DESCRIPTION	EXAMPLES	HYPOTHETICAL SOLUTIONS
Clarity	The necessity of clear commands to create a VR scenario where the objectives are successful.	Low prior knowledge, some people have never worked with IPS and VR.	
User control and freedom	Connecting several users to a server needs clarity and convenience.	Fast to boot up and connect to server. Should not take up extra time to start VR.	A clickable link that opens IPS and connects to the server.
Resources for structure	The transition from different software needs to be streamlined to use the tool as an addition in meetings.	Eliminate time spent on converting files and have updated files to set up in IPS when wanted.	Switch program to work with or dedicated personnel to assist with converting files and set up VR
Hardware solutions for optimal use	The right equipment to reach the tools' full potential.	Bigger CAD files make VR slow and reduces the feeling of immersion.	Graphic card good enough to handle big cad files.
Easy access for time efficiency	Enabling the potential of remote access would create a higher willingness for integrating the process.	Hardwear sufficient for every interested part – at desk or easy access to VR lab.	

Table 4.4: Software functions

PRINCIPLES	DESCRIPTION	EXAMPLES	HYPOTHETICAL SOLUTIONS
Predictability	Manufacturability and serviceability of the assembly.	Create a time sequence for measuring time for service/assembly.	There is a partly solution already with body motion planning.
Clarity for visual representation	The interface will clearly present objects of interest to manipulate in contrast to the assembly. Incorporate a meeting scenario and present ideas in the VR space.	Highlight part of interest to manipulate and analyze Sketch in the VR space to further explain ideas.	By interacting with objects, they should be highlighted by all participants. Able to create 3D drawings in VR.
User support	Create access to incorporate in manufacturing to give assistance to operators	Live contact with operators to follow up on the initial stages of manufacturing process.	
Access for blueprints and administrative actions	To instantly incorporate feedback in the design.	Direct changes after evaluating the physical parts.	
Direct feedback	Introduce real time simulations and analysis over thermal properties.	Viewing thermal signatures to see its implications.	
Reality applicability	To get a deeper understanding over the practical procedure and applicability for manufacturing.	Involve physical objects to get haptic feedback.	Mixed reality.

4.2 Empirical study

4.2.1 Single-user demo

The first scenario, figure 4.3, involved the assembly of an engine damper. Participants found the assembly process to be overall quite difficult. It was notably challenging to align and place the parts correctly. There was a significant deviation between the desktop simulation and the real-world assembly. The desktop simulation made the task appear easier than it actually was, which could lead to underestimating the difficulties involved in real-life assembly. Participants had the opportunity for this scenario to physically interact with the engine damper part, as a physical prototype. This resulted in a discussion about the weight of the part. Feeling the actual parts allowed them to appreciate the weight and size, leading to a greater understanding of the real-world challenges. They noted that the engine damper was quite heavy and in a real assembly scenario, many might prefer to use both hands to manage the weight effectively.

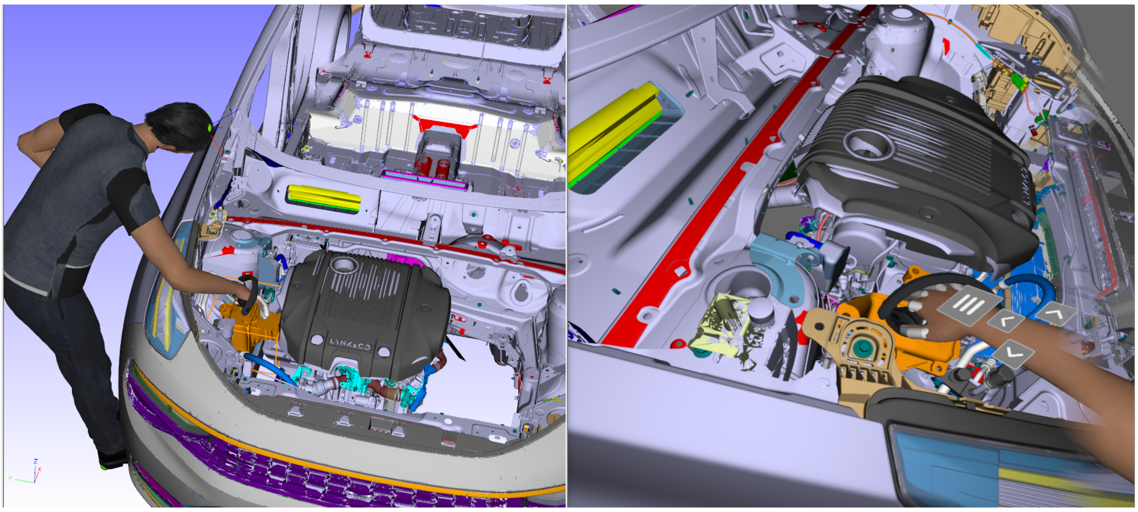


Figure 4.3: Scenario 1, left: desktop view, right: VR view, *Source: Screenshot from IPS, "Lynk & Co 01".*

The second scenario, figure 4.4, focused on the assembly of a front window. Participants struggled with visibility, specifically not being able to see the far side of the window, including the second guide pin, which was too far away. This made it challenging to properly align the window during the assembly process, ensuring the window remained parallel and correctly positioned. The desktop simulation made it look very easy in comparison. The VR simulation felt unrealistic for participants since the real assembly process typically requires two people. Performing the task alone in VR did not accurately reflect the collaborative nature of the actual assembly.

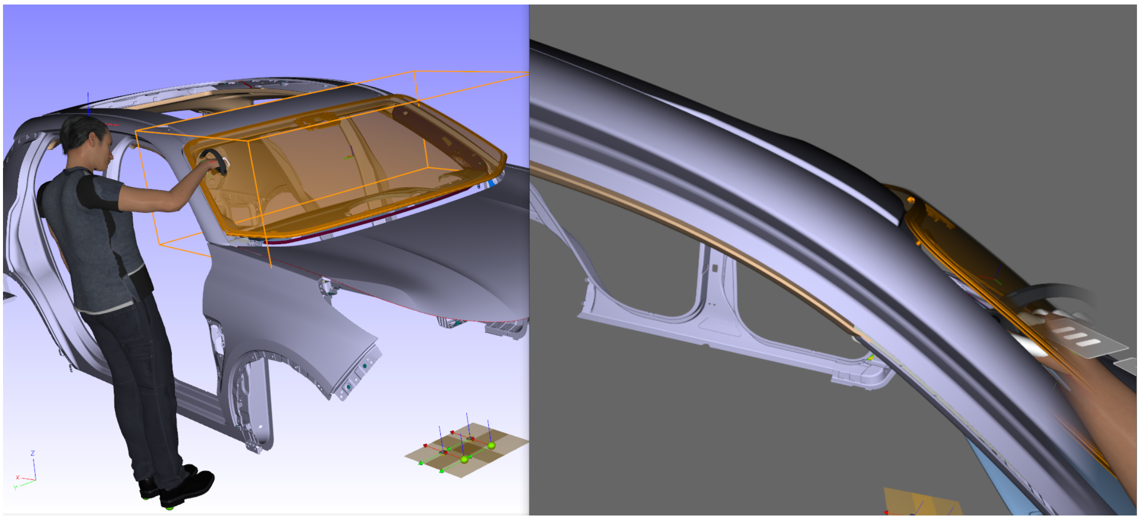


Figure 4.4: Scenario 2, left: desktop view, right: VR view, *Source: Screenshot from IPS, "Lynk & Co 01".*

The third scenario, figue 4.5, focused on assembling a plastic cover underneath the car. Participants faced significant difficulties based on their height. Taller individuals had to stand to the side of the car, which made it challenging to see where to position the cover correctly. Without haptic feedback this was extremely hard. On the other hand, shorter individuals struggled to reach the assembly point somewhat comfortably. Participants found the task physically demanding. The awkward positions required to see and reach the assembly point led to general discomfort and strain on their bodies.

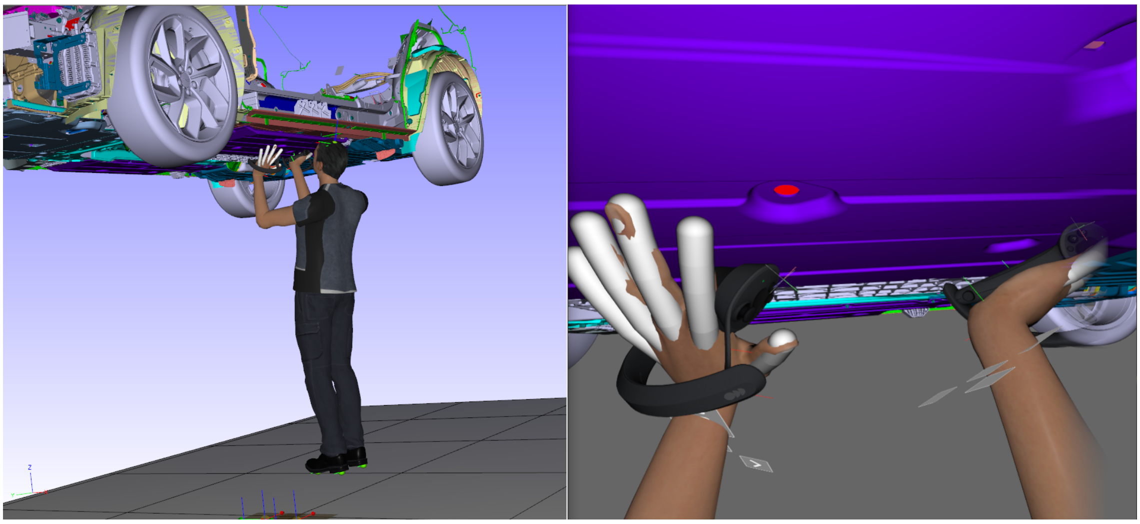


Figure 4.5: Scenario 3, left: desktop view, right: VR view. *Source: Screenshot from IPS, "Lynk & Co 01".*

During the demo, participants provided valuable feedback on their experience. As expected, everything did not go smoothly since not all participants were familiar with IPS VR. They experienced that the immersive feeling could be improved by moving where the hand grabs the parts. By default settings, there is a coordinate system above the VR controller (in VR) that needs to be inside the object when grabbing it. This results in the part "floating" above the hands instead of being in the hand, see figure 4.6. Recommendation from the participant is to move the coordinate system into the hand's palm instead, increasing the immersive feeling.

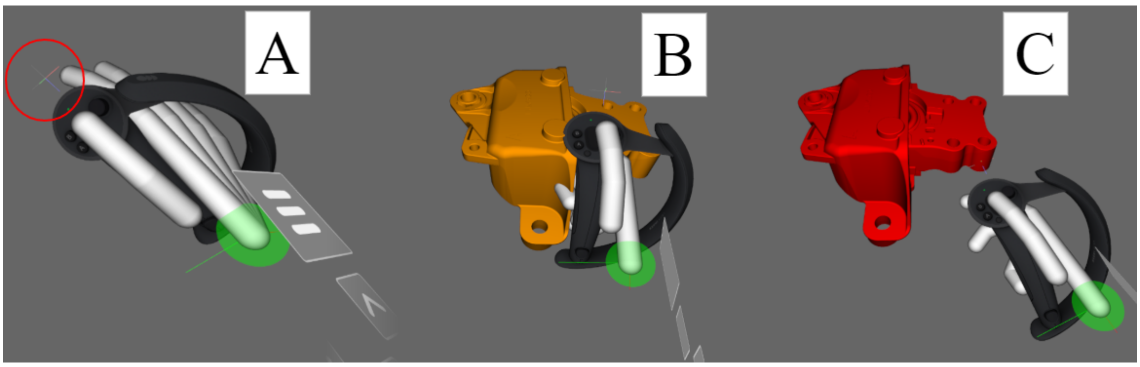


Figure 4.6: (A) highlights where the coordinate system is located above the controller. (B) shows when the hand are inside the part, but not grabbing the part. (C) demonstrates when the coordinate system is inside the part which makes it red and indicates that the part could be grabbed. *Source: Screenshot from IPS, "Lynk & Co 01".*

Participants expressed the need for haptic feedback when doing the assembly. The lack of haptic feedback made it hard for participants to feel where the part was and how it behaved during placement. This also made it difficult to see and understand exactly where parts collided with others, affecting their ability to make precise adjustments. To counteract this challenge a prototype stand was used to simulate where the car body is during the assembly, see figure 4.7. This was highly appreciated by the participants and allowed them to get a better understanding of how far away the part is assembled and how much they need to bend their body.

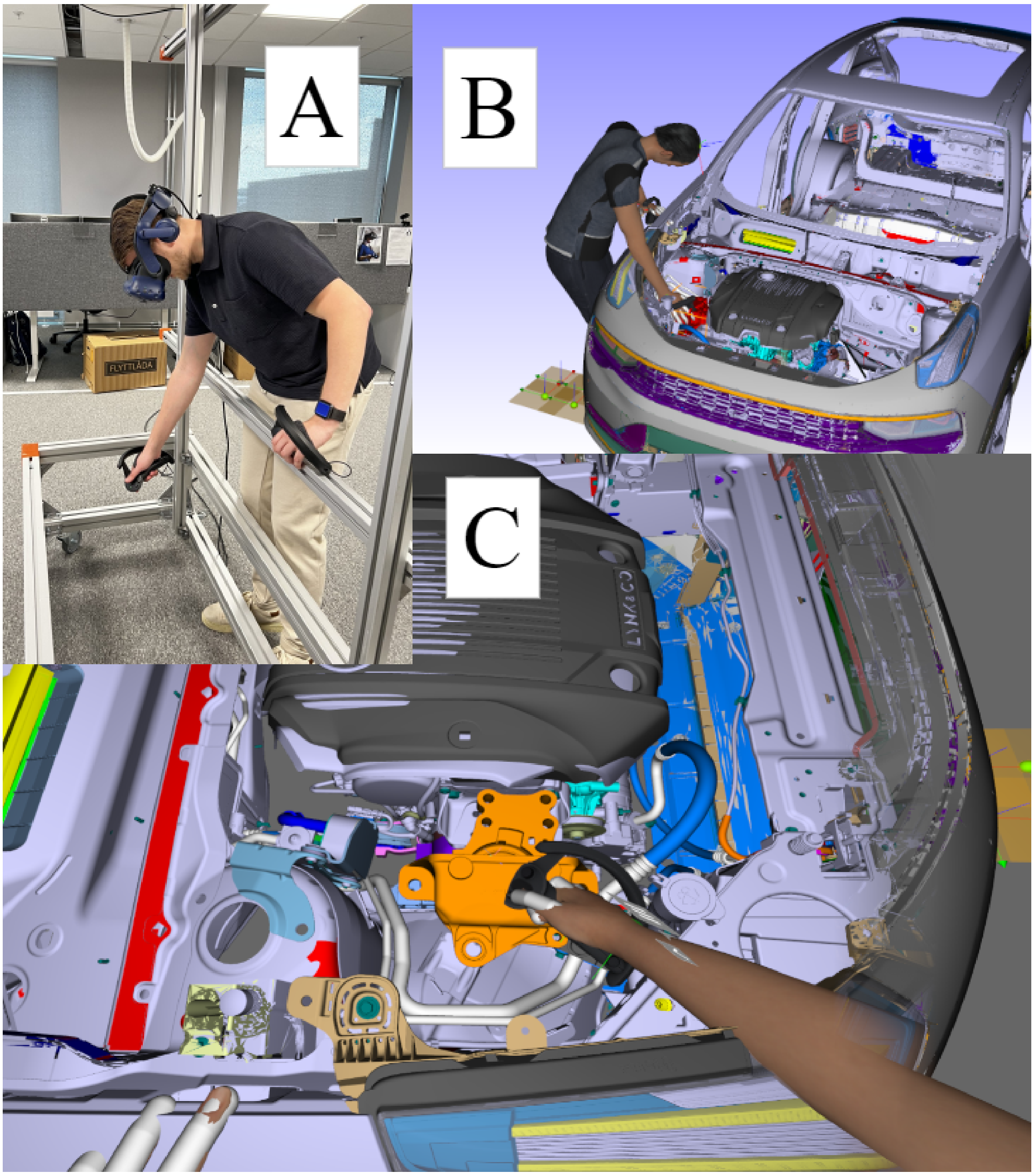


Figure 4.7: (A) is real life where the participant stand next to the stand and holds the left hand on it for support. (B) is IPS desktop where the participant is represented as a manikin. (C) is the view of what the participant can see in VR. *Source: Screenshot from IPS, "Lynk & Co 01".*

The data collection done during the demos is a representation over the information retrieval from the different methods for the same use cases. The survey visualize the direct correlation between understanding obstacles and the necessary information to carry out the physical assembly. The graphs represent the participants experience during the workshop. Which gives a percentage on how well they felt each method was serving the purpose and contribute to a comprehensive analysis over the assembly sequence.

The survey was divided into 3 parts with similar questions, were the participants rate (on a Likert scale ranging from "Strongly disagree" to "Strongly agree") how well the statement match their experience. The answers are presented in figure 4.8-4.10 bellow.

Part 1, figure 4.8. These answers are linked to the first scenario (engine damper) and evaluates their experience in VR and from desktop simulation. It's clear that many of the participants are unanimous regarding their experiance in VR. Only

In the first use case when using VR in assembling the engine damper and understanding weather the part could be assembled or not, 75 % strongly agreed with the statement and 25 % somewhat agreed. For the desktop simulation 37,5 % each somewhat agreed and strongly agreed. While 12,5 somewhat disagreed or neither agreed nor disagreed.

With identifying the issues 62,5 % using VR strongly agreed with the statement, while 37,5 % somewhat agreed. For desktop simulation, the result showed that 25 % strongly disagreed while 37,5 somewhat disagreed. 12,5 % each answered somewhat agreed, strongly agreed, or neither agreed nor disagreed.

For the ergonomic input, 75 % of the participants somewhat disagreed with the statement of being able to assemble without feeling any discomfort while 12,5 each strongly agreed, or neither agreed nor disagreed. In the desktop simulation 37,5 % somewhat disagreed, or neither disagreed nor agreed. 25 % somewhat agreed.

In VR the 62,5 % of the participants determined that they could see the part the whole time as well as understanding where the part clashed against other parts. 12,5 % strongly agreed, somewhat disagreed, or neither agreed nor disagreed. In contrast to the desktop simulation 62,5 % somewhat disagreed with the statement, while 12,5 % somewhat agreed and 25 % strongly agreed.

For the time necessary to assemble, 100 % in VR determined to get an indication over how long time the assembly procedure took. While for the desktop simulation, 25 % strongly disagreed with the statement, 37,5 % each somewhat agreed or disagreed.

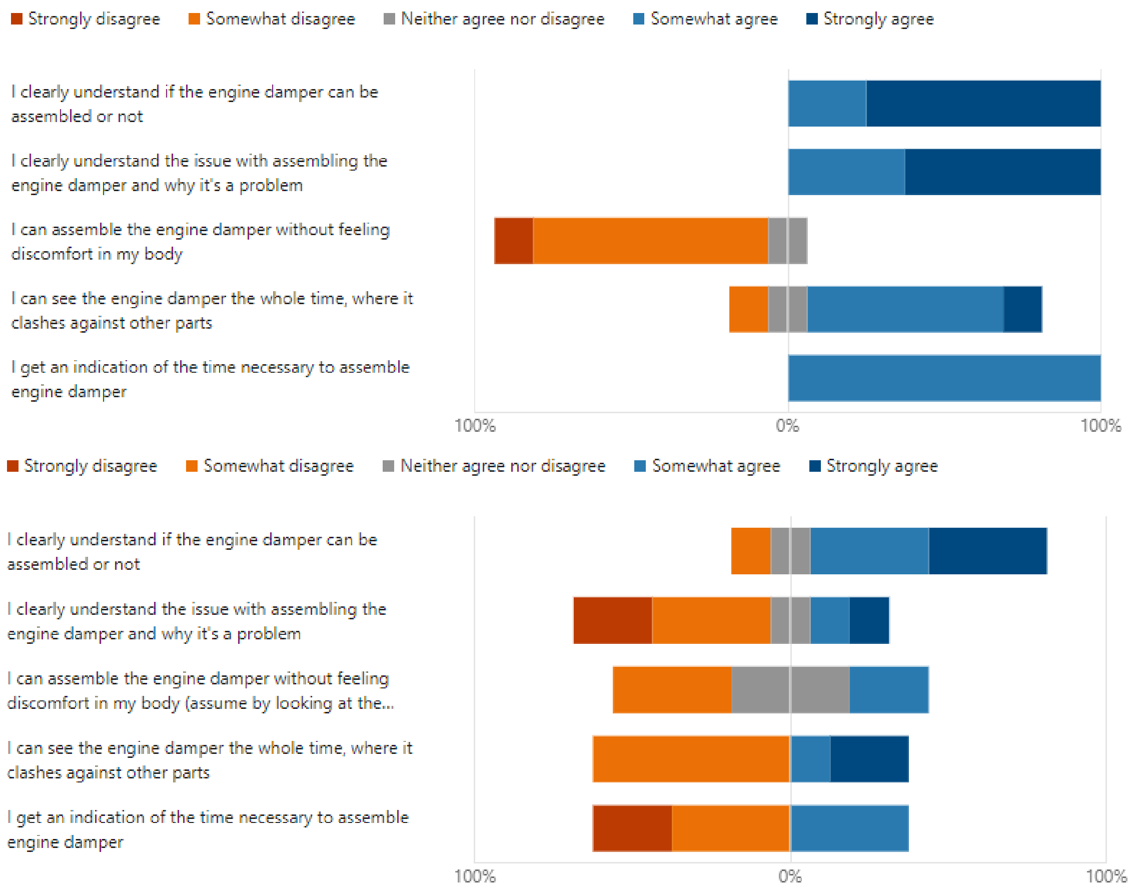


Figure 4.8: Engine damper, first set of questions are experience in VR, second set of questions are desktop simulation. *Source: Survey conducted by the research team using Microsoft Forms.*

Part 2, figure 4.9. These answers are linked to the second scenario (front window) and evaluates their experience in VR and from desktop simulation.

For the front window VR 50 % strongly agreed with understanding if the part could be assembled or not while 37,5 % somewhat agreed, and only 12,5 % somewhat disagreed with the statement. For desktop simulation 62,5 % somewhat agreed, while 37,5 % strongly agreed.

Question 2, if participant could understand the issues with assembling the wind shield or not. In VR 50 % strongly agreed 25 %, and 12,5 % each somewhat disagreed, or neither disagreed nor agreed. For desktop simulation 50 % somewhat disagreed with the statement while 12,5 each strongly disagreed and somewhat agreed. 25 % neither agreed nor disagreed.

For the ergonomic assessment the participants when they used VR, 50 % somewhat agreed with the statement they could assemble the part without feeling discomfort. 12,5 % strongly agreed, while 12,5 each strongly disagreed, or neither agreed nor disagreed. In desktop simulation 25 % somewhat disagreed, 50 % somewhat agreed, and 12,5 strongly agreed or neither agreed nor disagreed.

The view point for the VR scenario 37,5 % strongly disagreed with being able to see the window the whole time and understanding where the clashes where. 12,5 % somewhat agreed, disagreed and strongly agreed. In the desktop simulation 50 % somewhat agreed and 25 % strongly agreed whiler 12,5 % neither disagreed nor agreed or somewhat disagreed.

For understanding of how long time the assembly procedure would take, VR showed that 75 % somewhat agreed while the rest neither agreed nor disagreed. The desktop simulation indicated that 25% each somewhat disagreed or strongly disagreed, while the rest somewhat agreed.

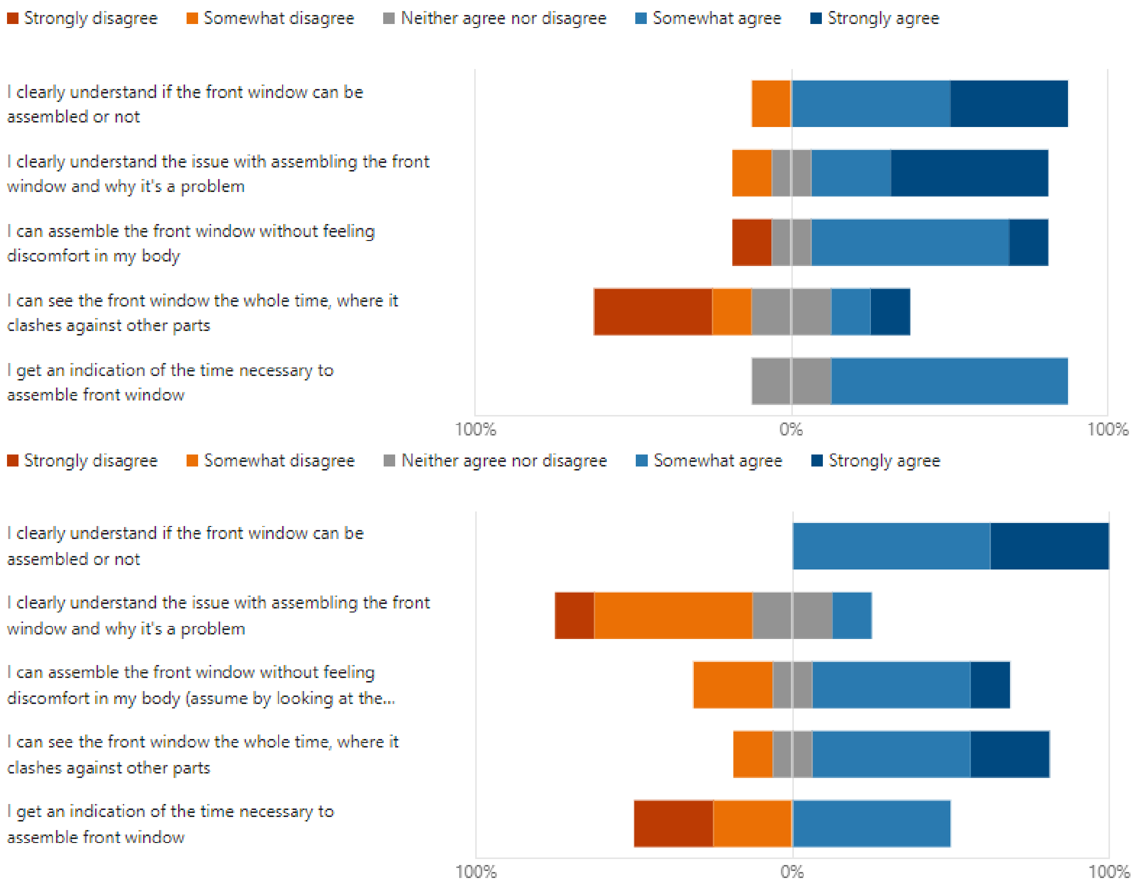


Figure 4.9: Front window, first set of questions are experience in VR, second set of questions are desktop simulation. *Source: Survey conducted by the research team using Microsoft Forms.*

Part 3, figure 4.10. These answers are linked to the third scenario (plastic cover) and evaluates their experience in VR and from desktop simulation.

The result for the third use-case have similar trends to each other. 100 % of the participants determined the clarity to be sufficient to understand if the part could be assembled or not. Desktop simulation divided the answers equally between somewhat agree and strongly agree. But VR simulation gave a result where only 12,5 % strongly agreed.

Second question gave the same result where 100% agreed with the statement of the question. For VR 62,5% strongly agreed, and a similar result could be collected from the desktop simulation where 50 % of the participants strongly agreed.

In the ergonomic assessment of the assembly sequence people could see or feel the discomfort with the assembly sequence. For VR 12,5 % did not feel any discomfort at all. While 75 % felt a high discomfort assembling the part. In the desktop scenario 50 % strongly disagreed with the statement that the part could be assembled without feeling discomfort. 37,5 % somewhat disagreed while 12,5 % neither agreed nor disagreed.

For the VR view point 25% strongly disagreed, 50% somewhat disagreed, while 12,5 % each somewhat agreed with the statement. Desktop indicated that more people saw everything in the sequence due to 75 % somewhat agreed to the statement and only 12,5 % strongly disagreed.

For an indication over how long the assembly procedure would take, 50 % somewhat agreed with the statement over how much time it would require to assemble the part. 25 % strongly agreed while 12,5 % each strongly disagreed or neither agreed nor disagreed.

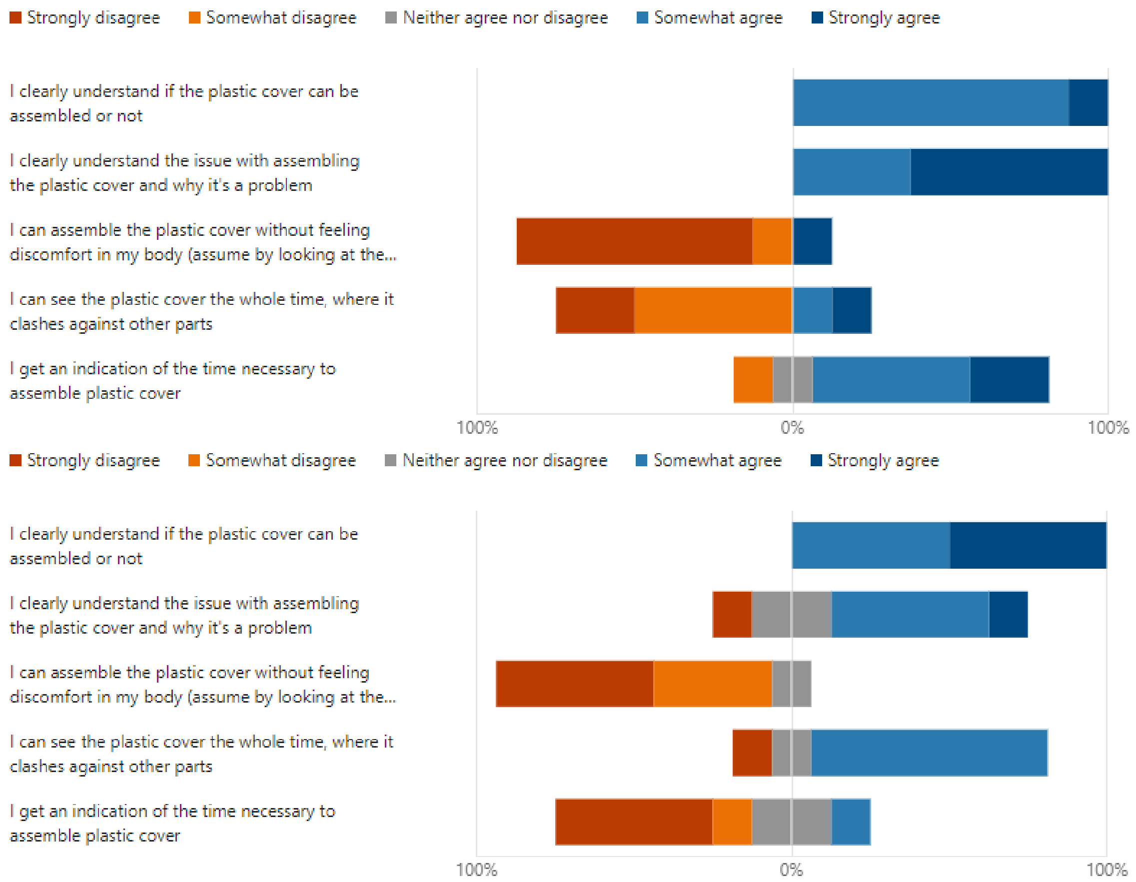


Figure 4.10: Plastic cover, first set of questions are experience in VR, second set of questions are desktop simulation. *Source: Survey conducted by the research team using Microsoft Forms.*

4.2.2 T-test

To evaluate which condition there was a significant difference between, a T-test was made. The Null hypothesis is that it is not any difference in knowledge understanding between the two methods of simulation. While the contradictory claim would be that it is a difference. Equation 2.4 is used to calculate the p-value. In a T-test each number that is below 0,05 would be determined to have a significant difference. So for instance Question 2 & 5 indicated lower numbers then the other questions. Therefor these questions had a significant difference in ability to acquire knowledge between desktop simulation and VR simulation.

Table 4.5: P-values for VR and Desktop

Use case	Question 1	Question 2	Question 3	Question 4	Question 5
Engine Damper	0.059982178	0.001633315	0.014089007	0.065154402	0.007122877
Front Window	0.270274467	0.002227342	0.41406394	0.026186123	0.043565059
Plastic Cover	0.061759562	0.017881579	0.5	0.047497813	0.000247297

As seen above in the table, some question had different distinctions depending on the use case. Question 3 indicated a high difference in the engine damper scenario while question 4 showed that the front window and plastic cover scenario had significant differences. For question 1 there was no lower numbers then 0,05 and therefor an indication that the null hypothesis where correct.

4.2.3 Multi-user platform

The multi-user platform is a web-based platform instead of the traditional desktop app. To access the software you simply press a link on the device witch takes you to a sign in screen where the user logs in to their accont. Then you are redirected to the multi-user window as seen in figure 4.11, no need to download anything or navigate between which simulation model that are going to be evaluated.

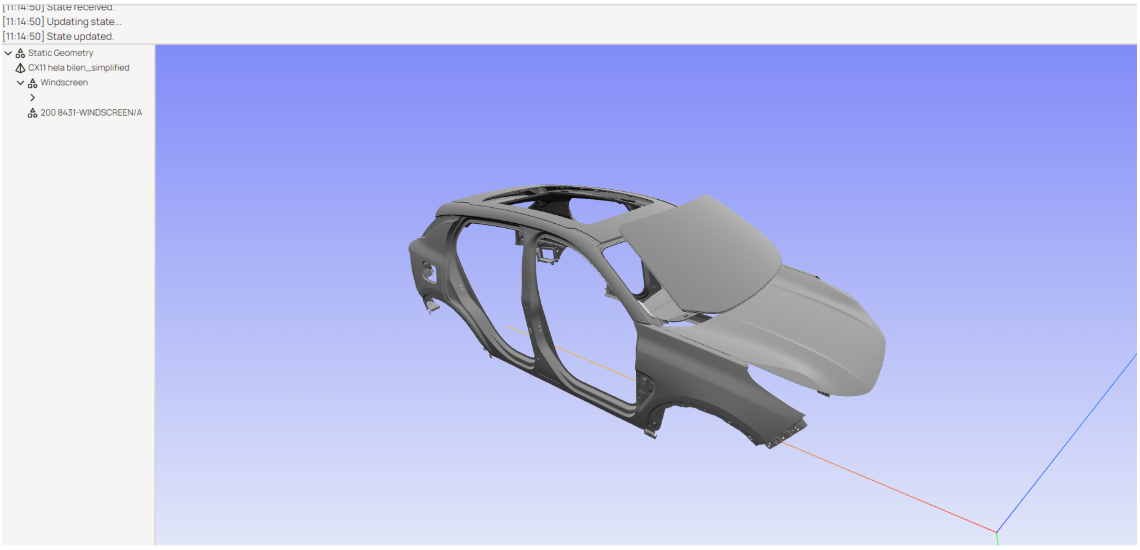


Figure 4.11: Web-based multi-user platform. *Source: Screenshot from IPS multi-user platform, "Lynk & Co 01".*

In order to evaluate the multi-user software in a structured way, a protocol was created. The protocol contains functions gathered from FCCs function list, appendix [B], on the software, interviews with employees at Zeekr Technology EU, table [4.3, 4.4] and PLENUM-project function list, appendix [C]. Duplicates and functions not feasible in IPS were removed. The filled in protocol with comments are showed in table 4.6 below.

Table 4.6: Protocol

Protocol - Empirical studie

Functions	OK	NOK	Comment
Server			
Enable/Disable tasks		X	
Start/Stop server	X		Manufacturer of software moderates this function
Join/disconnect and rejoin server	X		Join server by clicking the link and log in with aquired account
Reload state	X		Manufacturer of software moderates this function
IPS Functions & Virtual Relity			
Add/remove objects	X		Manufacturer of software moderates this function
Static geometry	X		Manufacturer of software moderates this function
Rigid bodies		X	Can't interract with model
Cable-view		X	
Manipulation Using the HMD (VR view only)		X	VR is not integrated yet
Multi-User			
Add/remove objects		X	Participants are not able to add/remove objects
Static geometry		X	Participants are not able to interract with model
Rigid bodies		X	Participants are not able to interract with model
Cable-view		X	
Manipulation desktop and VR		X	Participants are not able to manipulate desktop or VR
Software functions (from interviews)			
Time measurements		X	Participants can not measure time in the software
Highlight parts of interest		X	Participants can highlight parts in their own space but it will not light up for others
3D drawings in the 3D space		X	Function not developed
Properties such as Thermal condistions		X	Function not developed
Functionlist PLENUM (prio Zeekr)			
F-10: Participants can have diffrent roles, interract with diffrent objects		X	Function not developed
F-17: Objects behave like the physical part, cables is lifted or handled by multiple people		X	Function not developed
F-30: Ergonomic risk during simulated task. Post-XR assessment		X	Function not developed
F-34: Be a manikin in VR, Steer a manikin in VR and Steer a manikin from desktop		X	Function not developed
F-49: Teleport in Z-axis		X	Function not developed

The multi-user platform are in a very early development stage and many intended functions are not yet available to the researchers. Due to this, many functions are moderated by the supplier of the demo, FCC. FCC can start and stop the server, add and remove models and also reload the state. As a participant of the server you are only able to join/disconnect from the server. While in the server you are able to look around and zoom in/out. There is a possibility to light up objects by clicking on them, however the objects only lights up for that person, not for the other participants connected to the server. There is currently no functions integrated that enables manipulation of parts. The model has an IPS familiar appearance, however there is not much other reassembles since there are no additional buttons to press like path planner, create solid, create manikin, etc. Another crucial function not yet in the multi-user demo are virtual reality. There is no way to connect VR and enter the simulation like you can in the regular IPS software.

5 Discussion

5.1 Methodology

The initial aim with the project was to create a framework for an new Multi-user VR platform to enhance and evaluate collaboration between stakeholders in an design meeting. Due to the program being to immature for any relevant analysis, the objectives had to transition into a study about available technology involving the current methods for simulation of assembly procedures. VBE 2.0 as it stands for now is practised through feasibility simulation with a single user perspective were both desktop and first point of view VR is used for data collection. These two methods provide different possibilities to enhance understanding of an assembly procedure. Therefore it made their features highly relevant to explore and understand the different immersion levels to retrieve a realistic perspective on the aspects of assembling. Unfortunately leaving the multi-user perspective also meant that certain objectives with the interviews got irrelevant since it was impossible to validate. Instead the analysis of the interview became a foundation to the exploration between current VR method compared to the non-immersive simulation done on desktop mode. The change of the purpose for the interviews did not necessary have a negative impact project. Since many aspects relevant for VR, simulation, and design meetings were discussed here, a holistic perspective were also covered and the interviewees gave input in how different tools could be used in a value adding way.

5.2 Interviews

The term design review is broad and means different things depending on whom you're speaking too. At Zeekr Technology Europe DR are used as a meeting where designers sit down with their stakeholder or supervisor and evaluate the work they have done. It's most of the time one-to-one during these meetings, where they follow a checklist to answer if the CAD is OK or NOK. On rare occasions CAD software is used, but most of the time not. For that reason, DR isn't interesting for the project and won't draw any benefit from the multi-user platform. The collaborative purpose of a multi-user platform was difficult to find its usefulness in this context due to the lack of interested parties in the design work. Since simply the design of the part was evaluated in the development process a cad file was sufficient to make the analysis on. To put extra time into setting up a VR demo for a part was unwanted by the workers due to lack of potential it deemed to have. Time and accessibility of this technique was the major critic that raised during these interviews. In order to reach a full potential of a immersive setting more advanced AR tools was discussed. More so to develop the meetings where interaction could be made more realistic by increasing the feeling of sitting in the same room.

VIM and VBE are conducted similarly to each other where the engineers discuss with stakeholders and go through design for various parts of the vehicle. But VBE focuses on the feasibility of the assembly while VIM focuses more on how vehicle parts fit together. Both VIM and VBE have bigger meetings with many participants, either online through Teams or Teams participants combined with people being there in person. VBE has come further when comparing the modern technologies used for these meetings. With VBE 2.0, one person can share the screen to show the participants the simulation, the excel sheet with questions and the VR-view. While VIM and DR are done more like VBE 1.0, where one person shares the design on Teamcenter which makes it hard for the other participants to understand sometimes.

When looking back at figure 4.2 explaining the challenges experienced during the design meetings it's clear that some of them are shared and some are exclusive to VIM. This might be due to the technologies used by the participants. Problems like operator size and reachability are not an issue during VBE meetings, it could be because they are using IPS, where you can add manikins with the IMMA tool where all kinds of sizes of humans can be tested. The same tool combined with path planning would also eliminate the challenge regearing reachability, where the participants think it's hard to see if operators can reach screws with tools where access is limited.

Hidden assemblies where it's hard to determine if an assembly is visible by the operator or if something is in the way, are a challenge both VIM and VBE sometimes experience. It's hard when just looking at a CAD from one shared view over teams. To eliminate this problem there is a need for a physical prototype, or the cheaper solution via VR testing. By putting yourself in the operators position trying to assemble the part in VR you can easily see if there are parts in the way blocking the vision. With a multi-user tool, several people would also be able to test the assembly and together decide if the movement is feasible or not. The multi-user tool would also eliminate the last 2 shared challenges, limited view and not able to manipulate. If everyone in the meeting has the CAD open on their computer, they can decide on their own where to position the camera. This also enables them to manipulate objects and add/change parts to their liking.

5.3 Multi-User

To use the multi-user software, users simply need to click a link to be directed to the platform with the desired simulation. This is a highly sought-after feature for the targeted audience. The interviewees expressed a strong preference for user-friendly software. Providing a link for meeting invitations simplifies the implementation process. However, the multi-user platform currently offers limited functionality. When using the software as a client, the only available features are viewing the model and selecting objects. This can partially address the challenge of a "limited view," but without VR support, participants are restricted to viewing the model on a desktop screen and cannot enter VR for a closer look. Many of the common challenges experienced during VIM and VBE will remain unresolved until future software updates are released. As indicated in Table 4.6, many functions are not yet operational. Additionally, numerous functions from the FCC function list [B] are currently unavailable, which forms the basis of the software, leading to other functions not working yet.

Findings indicate the tool's applicability are lower than expected, partly due to incomplete development. Further investigations are recommended, with a revisit to the DS-I stage for adjustment. Doing the 3 scenarios on the multi-user platform was no option and would not give any value for the project or the stakeholders, hence the empirical studies continue as single-user demos.

5.4 Single-user investigation

The survey provide a comprehensive overview of the participants experiences and perceptions regarding both VR and desktop simulations. Analyzing the responses reveals a noticeable difference in the level of consensus between the two modes of simulation.

The demo revealed several insightful aspects regarding the use of IPS and VR for assembly tasks. One notable point was the varied levels of familiarity among participants with IPS and VR technology. This variation significantly influenced their experiences and feedback. Some participants had never used IPS or VR before. These individuals faced a steep learning curve and found it challenging to navigate and interact within the VR environment. Their feedback focused on the initial difficulties in getting accustomed to the technology, which likely influenced their perception of the immersive experience. For these participants, the immersive feeling was lower as they were still adapting to the VR interface and controls. Some participants had extensive experience working in VR, but with different software platforms. These individuals were adept at navigating virtual environments but noted differences in user interface and control mechanisms between IPS VR and other VR applications they had used. They suggested improvements such as relocating the coordinate system to the hand's palm for a more natural interaction with virtual objects and an indication for the user when an part is correctly assembled. Participants who were already familiar with IPS and VR, particularly those with experience in automotive assembly, provided more detailed feedback on specific aspects of the VR simulation. These users were able to compare the virtual assembly process directly with real-life scenarios, hence their feedback was more nuanced regarding the realism and practical applicability of the simulation.

When applying a T-test analysis on the survey, the most significant result could be drawn from the survey. For which specific aspect could immersive compared to non-immersive simulation have different ability in understanding issues for the future production line. For instance the understanding of problems occurring during the assembly was easier to understand in the VR simulation according to the survey. From observing the test participants had a different perspective in the space necessary to assemble a part. The gliding function gave them the immersive understanding of the obstacles and how handling the part in the correct path planing also meant a precise assembly not to collide with surrounding geometries.

Question 5 was considering how time was perceived in the different ways of simulation. The T-test proved that the result had a significant difference and a immersive simulation provide a bigger understanding how much time was required to carry out the assembly task. during the workshop, several participants claimed that the desktop simulation do not provide an insight in the small struggles navigating in tight spaces and change in posture. Therefor it differed in how much time and effort was necessary to put in to finalize the procedure.

Understanding the most significant aspects, where VR and desktop simulation differs the most is highly interesting for the usage in a VBE. Due to the fact that several interviewees deemed it important that VR provided a major impact to reap the benefits. Since VR is a time consuming activity that require the involvement of several people in a project where different departments needs to be integrated.

The first scenario (engine damper, figure 4.8) have the highest lever of unanimously when questioned regarding VR. A majority of participants agreed or strongly agreed on key aspects such as understanding the assembly feasibility, clarity on issues, and visibility of the engine damper during the assembly process. Most also disagree on statement 3. This is necessarily not an bad grade, it shows that all the participants experienced bad posture and came to the same conclusion. This unity suggests that VR provides a intuitive and immersive environment for users, enabling them to understand and engage with the simulation tasks. The responses to the second set of questions, focusing on the desktop simulation experience, show a wider variation. Participants opinions are less aligned, particularly regarding the comfort and ease of assembly, the ability to see and manage collisions and the overall clarity of the process. This difference could be due to the varying levels of familiarity and experience among participants with desktop simulations in IPS. Some users might be more accustomed to the VR environment, finding it easier to navigate and interact with, while others may still be adapting to desktop-based simulations. Many are also uncertain on statement 3 which indicates that the ergonomics are hard to determine by juts looking at the simulated paths.

The second scenario (front window, figure 4.9) the responses indicate a general agreement among participants, the unity is not as pronounced as in scenario 1. Participants feedback on the VR experience for the front window assembly is somewhat mixed. One significant challenge noted is that the assembly task in real life requires two operators, making it difficult to replicate accurately in a single-user VR setup. This limitation affects the realism and effectiveness of the simulation. Additionally, some participants found it challenging to see the front window during the assembly process, while others did not face this issue. This variation could be due to differences in the participants heights, which affects their line of sight and ability to view the assembly task clearly in VR. The desktop simulation responses indicate that more participants found it easier to understand the overall assembly process compared to VR. However, there is a notable gap in understanding the specific challenges associated with the assembly task, such as the difficulty of aligning the guide pins with the holes. This suggests that while desktop simulations may provide a clearer overview of the steps involved, they may not highlight the practical difficulties as effectively as VR. Participants also found it hard to estimate the time required for the assembly when using desktop simulation. This indicates a lack of engagement or a less immersive experience compared to VR, where the physical interaction might give a better sense of the time and effort needed.

The third scenario (plastic cover, figure 4.10), the survey results indicate consistent trends between VR and desktop simulations, but also highlights some differences in user experience. Both VR and desktop simulation provided participants with a comprehensive understanding of the assembly process. In VR 100% of the participants were able to determine if the part could be assembled and grasped the difficulties associated with the task. This high level of understanding is likely due to the immersive nature of VR, which allows users to interact with the assembly environment more realistically. The ergonomic assessment revealed significant discomfort among participants. Most participants experienced high discomfort during the assembly. This is indicative of the physical strain involved in performing the task in VR, which closely mimics real-life conditions. Many participants struggled to see the plastic plate during the assembly, highlighting a potential visibility issue in the VR simulation which could be related to the ergonomic issues, requiting the participant to bend their neck to uncomfortable positions even more. Everyone understands the assembly when using desktop simulation, however there is some uncertainties when understanding the issues with assembling the plastic plate. This suggests that desktop simulations, while effective in describing the basic steps, may lack the depth needed to communicate the practical obstacles. For this scenario the bad ergonomics were also very convincing when using the desktop, since it’s a very exhausting assembly.

The differences in survey responses emphasize the importance of user experience in simulation. VR offers a more immersive and consistent understanding of assembly tasks, while desktop simulations require improvements in user interface and additional training for participants less familiar with the software.

5.5 Further research

5.5.1 Multi-user platform

To fully use the multi-user platform, it must undergo a significant development. Currently the platform lacks several key functionalities that are essential for effective collaboration. All functionalities currently in single-user IPS should be in the multi-user platform as well. When all these tool are in place, future studies should aim to conduct comprehensive evaluations, to better understand the platform's strengths and limitations. These evaluations will provide critical insights into the necessary enhancements that can make the multi-user platform an indispensable tool for collaborative design and assembly tasks.

5.5.2 Single-user VR vs desktop simulation

The current study provides valuable insights into the differences between single-user VR and desktop simulation. However, a deeper analysis is required to fully understand the nuances of each method. First of all, more participants should be involved in the workshops to get a wider range of opinions. Secondly, more assembly scenarios should be introduced to help in gathering more generalized data. Lastly, more metrics such as cognitive load, user satisfaction and error rates could be evaluated to provide a more comprehensive comparison of the two methods. The workshops could also benefit from dividing the two methods into different workshops. One group of participants doing strictly IPS VR, and the other group doing strictly desktop simulation. This would enable a more independent result and the survey answers would not risk to be affected by other experiences from the other simulation method.

5.5.3 Enhancement of IPS Workflow

The current use of Industrial Path Solutions in design meetings and assembly planning is effective, but there is significant potential for improvement. From the interviews in the report, there are several suggestions on functions that could be implemented today using Lua scripting. For further research, it would be interesting to make a deeper analyze on these functions and evaluate which ones could be integrated in the commercial version of IPS.

6

Conclusion

How do VR simulation and desktop simulation compare in terms of effectiveness and user engagement during design meetings?

VR simulations offer a more immersive experience, allowing participants to interact with the assembly environment in a way that closely mimics real-life conditions. This leads to a better understanding of practical difficulties, such as spatial constraints and issue detection. Desktop simulations where often effective in describing basic steps, but lack the depth needed to communicate the practical obstacles and sometimes gives the perception of an assembly being easier than what it actually are. The differences in user experience and effectiveness between VR and desktop simulations highlight the potential benefits of using VR for design meetings. VR simulations provide a more intuitive and engaging environment, enabling participants to understand and address assembly challenges more effectively. However, they also require significant setup and familiarity, which can be a barrier for some users.

How is VBE, VIM and DR conducted today and what are the difficulties performing it?

The design meetings that would benefit from this work are VBE and VIM where the meetings are bigger with more participants and where visual aids such as simulation files are used. There are however a lot of challenges with these meetings today in terms of communication and expressing your thoughts to the rest of the meeting. With a new era with online meetings, sharing screens and talking with each other over the internet, problems like visualizing design proposals, hidden assemblies, limited views and not being able to manipulate the simulations, become more of a challenge. By addressing these challenges, we can improve the overall efficiency, understanding and decision-making processes within vehicle design and assembly reviews.

Why is VBE 3.0 necessary and what challenges does the multi-user need to resolve?

Developing a car involves numerous challenges, especially during the initial stages of production and design. Optimization of production lines and efficient communication are critical to assist engineers in understanding assembly sequences. There are a desire for closer collaboration with colleagues in Chinese production plants, which is currently limited. This enhanced collaboration can be achieved through

VR training and problem-solving sessions where critical design issues are addressed early on. VBE 3.0 aims to bridge this gap by providing an advanced, interactive and immersive platform for effective communication and collaboration. The multi-user platform must facilitate direct contact between global colleagues, enabling real-time communication and collaboration. It should help in clearly explaining assembly procedures, allowing for immediate feedback and adjustments. The platform must have an intuitive and user-friendly interface with recognizable functions and built-in buttons for easier handling. Given that many team members are not accustomed to using IPS daily, the platform needs to mimic the layout and functionality of other CAD software to ensure easy adaptation. Launching simulations, accessing CAD files and connecting to servers should be straightforward and hassle-free.

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A

Interview guide

The interviews started of with the authors presenting themselves and what their thesis is about to give the interviewees some background to the subject, describing the purpose of the interview. The interviews followed the same structure with similar questions, only changing words depending on what topic was discussed (VBE/-DR/VIM):

1. Can you walk us through the typical process of conducting a VBE/DR/VIM at Zeekr Technology Europe?
   (a) What tools or methods are used to document and track the outcomes of VBE/DR/VIM?
   (b) What are the objectives in VBE/DR/VIM?
2. What criteria or factors are considered when determining whether a VBE/-DR/VIM is necessary?
3. Who typically participates in VBE/DR/VIM? Are there representatives from different departments or disciplines?
4. How are issues or concerns raised during VBE/DR/VIM addressed and resolved?
5. Is there usually miscommunication among the coworkers during VBE/DR/VIM?
   (a) For example, when someone tries to express their design change ideas.
   (b) When pointing at specific objects.

B

FCC Function list

- Cloud-based solution
  - Secure communication
  - Only for authenticated users
    - Microsoft Authenticator needed
- Server
  - Enable/disable tasks
  - Add/remove objects
  - Reload state
- Clients
  - Browser view
  - VR view
- Functionality
  - Both views
    - Visualization and concurrent manipulation of:
      - Static geometries
      - Rigid bodies
      - Cable-view
  - VR view only
    - Manipulation using the HMD and controllers
  - Browser view only
    - Show properties (ex meta data)
    - Manipulation using mouse and keyboard
    - Scene graph
    - An IPS familiar appearance
    - Help/Info
    - Attendees
      - “Who Am I”
      - List of other persons

C

PLENUM Function list

Function list delivered from PLENUM-project. Zeekr Technology EU, VOLVO and Scania participated in a vote for the most interesting functions. This master thesis focuses on the once highest rated from Zeekr Technology EU:

- F-7
- F-10
- F-17
- F-18
- F-30
- F-34
- F-44 (F38)
- F-49
- F-19
- F-42

PLENUM Function list:

- F-16: There should be a reset-function to re-orient participants if they have wandered off and gotten lost. To “re-spawn” them in the starting positions.
- F-28: Collaborative Tools: The XR environment should include tools to facilitate collaboration between attendees, such as virtual whiteboards, shared document editors, or virtual sticky notes.
- F-13: A miniature “map” displaying the user’s relative position and orientation of an object, assembly and the 3D-scene in relation to a user should be created, to help the user (especially when using the rescaling function to become miniature size, where there is a risk to get lost in the details).
- F-7: A simulated object in the form of a rigid body, flexible body (such as e.g. cables), mechanical parts (such as robots, co-bots, lifting tools), manikins, fixtures and tools (such as for measurements) should be able to be added in a user-friendly way to the simulation from a database of pre-tessellated objects.
- F-10: Objects in the XR-environment should include a hierarchy when loaded into the XR-environment, with write, read and view-only properties for different participants. This should be automatically assigned depending on the different roles of people in the meeting (leader, internal participants, external participants, spectators). Some participants can make changes only in the virtual environment, and one or several appointed users with privileged access can allow these changes to be saved into a master file.
- F-17: The XR-simulation should be able to do physics simulations of the kinetics and mechanics of virtual objects, like e.g., how a flexible part will behave

depending on how it is lifted, or how objects behave when being handled by multiple people at the same time (like seats, cable harnesses, engines).

- F-18: Real-Time Modifications of simulated objects: The XR environment should allow attendees to make changes to virtual objects or presentations in real-time, which are easily replicated in the original file providing a more interactive and dynamic experience.
- F-30: The system should highlight the ergonomic risks during the simulated task (using e.g., colour coding of body parts), and offer corrected ergonomic actions. This also includes recordings of the raw data collected from the manikins and users for a post-XR ergonomic assessment (e.g., joint angles, distances).
- F-34: A user should be able to choose one of the following three modes to occupy a manikin: 1- Be a manikin in VR, 2- Steer a manikin in VR, 3- Steer a manikin from a laptop/desktop
- F-44 (F-38): Privileged user(-s) should be able to have access to simulated objects to import and use during an AR session. This would allow the AR user with HDM to display, move, and manipulate the objects. (AR button for IPS)
- F-49: Users should have the option of "teleporting" in the z-axis (for easier access and view to certain objects in the simulation)
- F-5: The XR-room should enable spectators connecting with a regular screen in a "fly mode", where they can move freely in the 3-dimensional space.
- F-14: Everyone attending the XR meeting should be able to point towards a specific part of the product, highlight or mark it in order to ask questions and clarifications
- F-19: Real-Time Modifications of production parameters: The XR-environment should allow attendees to make changes in the movement of mechanism tools with different degrees of freedom (such as robots, co-bots and lifting tools), which should result in automatic re-programming of mechanism tools in real-time, providing a more interactive and dynamic experience.
- F-20: The XR-environment should have enough accuracy to support precision modifications (in terms of e.g., moving a fixture by millimetres). This should be done by being able to move something in increments.
- F-21: Modification of mechanism tools with different degrees of freedom using inverse kinematics: The mechanism tools (robots, co-bots, lifting tools, etc) of varying degrees of freedom integrated in the VR environment should be able to be modified by the user simply pulling e.g., a robot arm to where it should be positioned, and this should results in automatic programming of the robot arm using reverse kinematics.
- F-22: Voice recognition and commands: The XR environment should be able to recognize voice commands, allowing attendees to execute a command such as: "start recording" and "stop recording". This would allow a leader of a session to be able to both lead it from XR and do this, without having to exit the XR-session.
- F-25: Cross-Platform Compatibility: The XR environment should be compatible with a range of devices, including VR headsets, AR glasses, laptops, smartphones, and tablets, to ensure that attendees can participate regardless

of the technology they have available

- F-26: Recording and Playback: The XR environment should provide a way to record sessions, allowing attendees to review the session later or share the recording with others who were unable to attend.
- F-27: File Sharing: The XR environment should provide an easy way for attendees to share files and other documents, such as meeting notes or design models.
- F-29: The system should be able to calculate strain that can be experienced by the user. For example, gravitational force exerted upon a user from either carrying an item, or from a being in specific posture when performing a task should be simulated and demonstrated in XR.
- F-32: Assessment of ergonomics considering the time aspect (frequency, magnitude and duration), and "full workday assessment" e.g. using RAMP or EAWS.
- F-33: The system should be able to provide an automatic report from the XR session, e.g. list of attendees, types of device used to attend the meeting, voice to text minutes. This should also include an "actionable list" that is generated automatically from the transcript, where it is marked "what needs to be done, and who needs to do what".
- F-42: The system should support an immersive environment and shared physical space that is platform independent. This implies that an AR-user should be able to make a 3D-capture of his or her local environment (using e.g., 3D-scanners or photogrammetry), which is automatically generating a 3D-environment. This 3D-environment will then mirror the physical environment of the AR-user and allow for people on remote to get a more embodied experience. They should be able to join using either XR-headsets or from a desktop, and this would then enable them to be able to move around freer, and not just be restricted to viewing the POV of the person wearing AR-glasses
- F-45: Using AR for factory layout planning, to see if a fixture, robot, operator, manikin, lifting tool etc. will fit and work in the production line
- F-47: Privileged users should be able to change their manikin's height, and anthropometrics of their manikin
- F-52: There is a direct connection between IPS and the robot programming environment supporting changes of parameters
- F-1: A simulated XR lobby, meeting room or production environment.
- F-2: The virtual meeting room or production environment is mapped to a physical meeting room or production environment with minimum requirements to change and adjust it to the physical counterpart.
- F-3: Users who will be in a XR meeting can choose/adjust/personalise a manikin as their avatar to represent them and their organisation
- F-4: The XR meeting room should be big enough to accommodate 10+ participants if needed (both in terms of having enough virtual room for the participants to meet without intruding on personal space, and in terms of computing power and network capacity).
- F-6: The XR attendees can choose to have signs instead of a manikin/avatar if they will only observe the meeting

- F-8: A 3D-CAD object should be able to be imported into the database of the XR-simulation and then tessellated into something that is viewable in XR
- F-9: The XR-environment should support different roles, with different agency: leader, internal participant, external participant, spectator. This should be automatically assigned as default, so that users do not need to put extra work into assigning different roles to different people. When a leader leaves the meeting, the leader roll should be automatically assigned to someone else in the meeting.
- F-11: All participants should be able to rescale themselves to giant or miniature size, to be able to get an alternative perspective on the simulated object.
- F-12: Those who have write-rights should be able to rescale the product in XR
- F-15: HMD-users who attend an XR meeting should be able to walk around the simulated product but should be prevented from walking or teleporting into a product.
- F-23: Voice recognition should also be able to be used for creating automatically transcribed meeting notes.
- F-24: Gesture Recognition: The XR environment should be able to recognize hand gestures, allowing attendees to interact with the virtual environment and each other in a natural and intuitive way. One problem with this is that different heights of users may cause problems when the origo of this is fixed to the user's head.
- F-31: Couple an ergonomic situation for an assembly operation to quality errors that occur in production because of poor ergonomics.
- F-35: The system should be able to offer a mechanism to make a poll and the outcomes during an XR session e.g., to record Yay/Nay votes on a suggested change the system should offer Yay/Nay feature to all the users with voting privilege. Using these features should be mapped to a specific change or task, so that it could be reviewed and understood after the XR meeting.
- F-36: The system should be able to offer a degree of body language of the avatars and manikins, to convey non-verbal communication that is often observed and experienced during face-to-face meetings (either online or in a physical space)
- F-37: The XR environment should offer additional rooms and spaces for the attendees to interact with each other beyond the specific meeting or task e.g., to socialise, have a break, team building, hold informal meetings with external partners, and to hold pre- and post-meeting activities to help with onboarding of those who are not fully familiar with XR
- F-38: The system should provide a robust security and privacy mechanism for data management
- F-39: The system should comply with GDPR
- F-40: The system should offer a "sandbox environment", where a user can test things without them affecting the real files or models. This would be an open environment where users can experiment and try out new things.
- F-43: The system should support an immersive environment and embodiment with avatars regardless of device – meaning that an AR-user should be able

to see those using VR-glasses or joining using desktop as avatars, and those users seeing the AR-user as an avatar.

- F-46: Privileged user(-s) should be able to leave a voice note connected to a CAD-drawing or simulated object that is being reviewed in VR
- F-48: Privileged user(-s) (e.g., production engineers) should be able to intuitively interaction to communicate changes to parameters
- F-50: When VR users interact with mechanism parts (not limited to robots), there should be sequence editor function where users can define different tasks, for example: when should products attach to the mechanism part TCP and when should part detach from the mechanism TCP and when should mechanism parts go back to original position (for example: if user press the reset button…)
- F-51: The system should be available to different groups of users within the organisation to access the material (during or post XR session) to co-design, review and suggest changes if need be e.g., maintenance personnel should have access to the new simulated product (e.g. fixture) to fix/review.

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