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Virtual reality in production development projects

Bachelor thesis in mechanical engineering

Albin Söderback
Vuong Nguyen

Department of Industrial and Materials Science
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2023
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Examiner: Prof. Björn Johansson, Department of Industrial and Materials Science
Supervisor: Clarissa A. González Chávez, Department of Industrial and Materials Science
External supervisor: Kåre Folkeson, Leander Koanders

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Department of Industrial and Materials Science

Chalmers University of Technology 2023

SE-412 96 Gothenburg

Telephone +46 31 772 1000

Department of Industrial and Materials Science

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Abstract

In industrial development, virtual reality (VR) is a tool with huge potential, especially as industries become increasingly digital. With the help of virtual reality, employees may perform otherwise dangerous manufacturing operations without getting hurt, or a designer might be able to discover problems with the production layout or model before it is assembled. Consequently, less expensive mistakes and rework occur, eventually saving the organizations money and lives.

This bachelor's thesis explored the topic "Virtual Reality in Production Development Projects "and was conducted at Virtual Manufacturing AB. This project examines the benefits of VR technology in development projects and how currently existing hardware and software can be used to implement a Virtual reality workspace. By implementing a Virtual reality workspace, this project aims to enable the design team at Virtual Manufacturing to review their model's scale and ergonomics in a more immersive way. This is accomplished with the help of hardware (Meta Quest) and software (Unreal Engine)

The findings presented in this thesis aim to empower both the organization and future engineers with the knowledge and insights needed to further harness the potential of VR in production projects.

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Keywords: Virtual Reality, VR, Manufacturing, Development, Production, Visualisation, Oculus, Level of Detail (LOD)

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Finally, We want to thank the developers behind Unreal Engine and Unity for providing us with the software we used throughout the project. Their user-friendly interfaces and powerful tools helped us accomplish our goal. Furthermore, we are grateful for their comprehensive guidelines and tutorials, which proved to be very helpful in resolving the technical challenges we encountered during the development.

Content

Abbreviations

VR: Virtual Reality

HMD: Head Mounted Device

RQ: Research Question

CAD: Computer Aid Design

STP or STEP: Standard for the Exchange of Product Model Data

GPU: Graphics processing unit

USB: Universal Serial Bus

HDMI: High Definition Multimedia Interface

3D: Three-Dimensional

NASA: National Aeronautics and Space Administration

CPU: Central Processing Unit

SDK: Software Development Kit

NDK: Native Development Kit

JDK: Java Development Kit

APK: Android Package Kit file format

DataPrep: Data preparation

FPS: Frames Per Second

HTC: High Tech Computer (company's name)

1. Introduction

1.1 Background

Virtual Manufacturing AB provides services related to lean manufacturing products and logistics development. They have been using virtual reality in their production development projects for years and now strive to develop a method for reviewing products in a virtual environment. The Assembly and Production Flow department will carry out this thesis work to create a VR setup to facilitate all product development projects.

The history of VR can be traced back to the early 1800s when Sir Charles Wheatstone created the earliest type of stereoscope by using a set of mirrors. However, the type of VR that we are most familiar with today, involving a digital head-mounted device (HMD), was developed in the 1960s. Since then, VR has become more accessible to the public, and more features have been built into the system [13].

Virtual reality in production development offers several different use cases and benefits, such as visualization, simulation, prototyping, and the ability to provide a realistic training experience. In other words, virtual reality may simulate risky or difficult conditions like a simulated manufacturing process or medical procedures for a surgeon, providing a secure and regulated environment for individuals to refine and enhance their competence. This can ultimately lead to improved outcomes and increased safety in the real world [1, 3].

VR may also be a handy educational tool, particularly in science and engineering, by enabling students to interact with and explore complex concepts in a highly immersive and interactive manner. VR can grant access to educational experiences that may be unfeasible or dangerous to experience in person, such as school education during the COVID-19 pandemic or in hazardous locations. Virtual reality's interactive and amusing nature makes studying more fun and engaging, allowing students to participate more actively in their knowledge and creating more motivation and passion. [3,14]

Although VR presents several potential advantages, it also poses some challenges. Motion sickness is among the most significant challenges, especially when it comes to experiences that require much movement or involve rapid shifts in perspective. Symptoms such as nausea, dizziness, headaches, and eye strain may arise as the brain receives conflicting information from the eyes, which perceive movement. At the same time, other sensory receptors indicate that the body is stationary. Concerns have also been raised concerning the long-term implications of VR use on the eyes, brain, and overall health. [3, 15, 16]

One of the challenges encountered during the development of this project was the high cost and difficulty of implementing VR technology. In order to be able to implement VR correctly, high-end computers, specialized hardware and software, and a high degree of technical competence in both hardware and software are required. This can pose a significant barrier for educational institutions and companies with limited budgets and technical skills.

1.2 Purpose and Aim and Research Questions

This thesis aims to develop a virtual reality workspace to help Virtual Manufacturing AB with the production development process. The purpose of the virtual workspace is to enable both the design team and the company's customers to review models on a real scale inside a virtual reality environment before the product is finished. This will be accomplished by assessing the software to select the optimal solution that fits the criteria and preferences of the stakeholders. The goal is to enable all Virtual Manufacturing projects to employ virtual reality as a tool and examine the benefits and issues connected with its usage.
The project intends to contribute to current knowledge on the benefits of employing virtual reality in production and development projects by answering the following research questions.

RQ.1 What are the technical requirements in order to implement a reusable virtual reality workspace to be used in production development projects?

RQ.2 What are the benefits of having VR as a tool in production development projects and what does it add to Virtual Manufacturing and their customer

RQ.3 How can the threshold to use virtual reality in production development projects be lowered and more easily used?

The insights will help Virtual Manufacturing improve their production development processes. These findings will be helpful to other businesses looking to implement virtual reality technology into their production development processes.

1.3 Scope and Limitations

This study has limitations that must be acknowledged to provide an accurate understanding of the project's scope. First, the project focuses on developing a primary method for implementing a reusable virtual reality workspace in production development projects. The initial goal is to establish a foundation for this workspace, and only if time permits will the virtual environment be further improved with the addition of various tools and advanced features. This constraint is necessary to achieve the core functionality within the project timeline.

Another limitation pertains to the hardware and software utilized in the project. The study is restricted to using hardware already available at the company, which limits the range of devices and capabilities that can be explored. Additionally, the software chosen for the project will be limited to those with which the research team or the company has at least a basic understanding. This constraint is in place to ensure that the project remains feasible within the given timeframe and resources, as learning new software tools from scratch can be time-consuming and challenging.

By acknowledging these limitations, the study maintains a realistic scope. It focuses on delivering a practical and achievable solution for the company while recognizing that future improvements and expansions could be made.

2. Theoretical background

2.1 Understanding Industry 4.0

Industry 4.0, also frequently called the "Fourth Industrial Revolution," has generated considerable interest among researchers and industry professionals. This revolution emphasizes the vital role of intelligent manufacturing, connecting computers and automation in new and innovative ways [6]. A cyber-physical system is established by adopting digital technologies for collecting and analyzing real-time data. The evolution of the Internet of Things (IoT), Cloud services, Big data, and analytics have enabled this revolution. "Industry 4.0, or the fourth industrial revolution", differs from previous revolutions because it combines technologies and their interactions across physical and digital domains. These technological advances allow companies to work more efficiently than ever." [6]. The implementation of Industry 4.0 technologies is still a research subject, with some studies proposing maturity models while others examining these technologies' impact on industrial performance [2].

2.2 Virtual Reality (VR) in Industry 4.0

Virtual reality (VR) has emerged as a transformative technology within the framework of Industry 4.0, offering innovative ways for businesses to optimize their operations, enhance training programs, and elevate customer engagement [3]. VR applications extend beyond gaming and entertainment to other sectors, such as athletic training, military simulations, and medical education [4]. Among the numerous benefits of implementing VR in Industry 4.0, digital twins and advanced training methodologies for the workforce are particularly noteworthy.

2.2.1 Digital Twins

Digital twins are computer-generated duplicates of real-world objects or procedures that can be utilized to simulate and optimize industrial operations. This technology minimizes the dependence on costly physical prototypes and reduces downtime [4]. For example, VR can be employed to simulate the behavior of machines within a factory setting, enabling engineers to proactively identify potential issues and, subsequently, make adjustments to optimize efficiency [5].

2.2.2 Training And Education

Another significant advantage of incorporating VR in Industry 4.0 is the potential for enhancing the training and education of the workforce. VR-powered simulations offer highly realistic training scenarios, equipping employees with the practical skills and knowledge to perform their tasks safely and competently. Additionally, VR can be utilized to develop interactive educational materials, resulting in a more immersive and compelling learning experience for workers [4,5].

2.3 VR Hardware and Software Description

The successful implementation of virtual reality (VR) in Industry 4.0 relies on selecting appropriate hardware and software. This section provides an overview of the various types of VR hardware, their intended applications, and a discussion of popular VR software, focusing on Unity and Unreal Engine.

2.3.1 Types of VR Hardware and Their Applications

Virtual reality technology relies on specialized hardware to create a fully immersive experience. There are three main types of VR hardware: head-mounted displays (HMDs), desktop VR, and projection-based systems.

Head-Mounted Displays (HMDs): HMDs are wearable devices that display stereoscopic images and track head movements to create an immersive experience. They are commonly used in gaming, training, and simulations [8]. The most popular HMDs include Oculus, HTC Vive, and PlayStation VR.

Desktop VR: Desktop VR utilizes computer monitors or TVs to display 3D content. While it is not as immersive as HMDs, it is more accessible and cost-effective, making it ideal for educational purposes, architectural visualization, and design applications [9].

Projection-based Systems: Projection-based systems project 3D content onto walls or screens to create a more immersive experience for multiple users. They are often used in collaborative design, scientific research, and large-scale simulations [10].

The technical requirements for VR hardware vary depending on the specific use case. However, they generally require a robust computer with a dedicated graphics card, high-speed internet connectivity, sufficient space for room-scale VR systems, a VR-ready operating system, and USB ports and HDMI or DisplayPort connections for connecting the VR headset and controllers to the computer [11].

2.3.2 Overview of VR Software and Use Cases

VR software, such as game engines and development platforms, allows creators to build immersive experiences for various applications. Unity and Unreal Engine are two widely used game engines in the VR industry, each with its own strengths and weaknesses.

2.3.2.1 Unity: Features, Examples, and Comparison

Unity is a flexible game engine that works on various platforms, including Windows, macOS, Android, iOS, and virtual reality devices. Its user-friendly interface and extensive asset library make it popular among developers. Unity has been used to create VR experiences in industries such as automotive and architecture [7]. For instance, it has been employed in designing VR training simulations for medical professionals [30]. However, unlike Unreal Engine, Unity's graphics may need to be more realistic, potentially affecting the level of immersion in some applications. Unity offers a variety of pre-built assets and templates, including character models, terrain, and lighting, which can be employed to expedite the development process.

One of the key advantages of using Unity for VR creation is its simplicity. The engine features a user-friendly interface allowing developers to quickly create and modify 3D objects and environments. Additionally, Unity has an active community of developers who share knowledge and support one another through forums, tutorials, and other resources [29].

Another advantage of using Unity for VR development is its cross-platform compatibility. With Unity, developers can create VR applications compatible with diverse hardware platforms, such as smartphones, gaming consoles, and desktop computers.

2.3.2.2 Unreal Engine: Features, Examples, and Comparison

Unreal Engine is another powerful game engine with advanced graphics capabilities, making it suitable for applications requiring high-quality visuals [28]. It has been employed in various sectors, such as cinema, automotive, and aerospace. Unreal Engine's Blueprint system enables users with limited programming skills to create complex interactions and behaviors [29]. However, it may be more resource-intensive than Unity, potentially limiting its use on lower-end hardware.

One of the main advantages of using Unreal Engine for VR development is its advanced graphics capabilities. The Engine provides advanced lighting and shading features that allow developers to create highly realistic environments. Additionally, Unreal Engine supports high-fidelity audio and provides advanced physics simulations [29]

Unreal Engine also offers a range of tools for optimizing VR performance. For example, the Engine provides an "Instanced Stereo" feature allowing more efficient rendering of VR scenes [31]. Unreal Engine also has a large community of developers who share knowledge and support one another through forums, tutorials, and other resources.

2.3.3 Virtual environment concept description

To design a virtual environment, it is necessary to possess a mix of technical skills in Static meshes, physics simulation, visual scripting, locomotion, frame rate, and level of detail. In addition, a deep understanding of user experience design and human-computer interaction principles is necessary to ensure an immersive and engaging experience for users.

Static meshes are a three-dimensional digital representation of a product or environment developed by independent 3D modeling software and imported and stored in the game engine as packages. 3D models can range in complexity from simple geometric patterns to incredibly detailed reproductions of real-world objects and surroundings. The most significant advantage of using static meshes is that they render very quickly compared to other 3D formats [17].

Physics is commonly utilized in games to create realistic interactions between diverse items in a virtual reality environment. Physics simulation may be used by game creators to model many physical laws, such as how different objects react according to their attributes and gravity when they collide with each other. It is also possible to imitate automobile sector objects such as suspensions, tires, and so on [18].

Visual scripting is a programming technique that allows developers to construct complicated game logic and behavior without any expertise in coding. Instead of typical text-based code, developers create it by dragging and dropping distinct blocks, or nodes, that represent code components. This improves cooperation among engineers who lack programming skills [19, 20].

Locomotion is a function offered by game engines in virtual reality that allows players to move around in the digital world. Physical locomotion and artificial locomotion are the two forms of locomotion. The physical locomotion enables users to manage their mobility in the digital world by mimicking real-world actions in a predefined game region. The artificial locomotion, on the other hand, lets users navigate the VR world with the help of a controller. This provides an opportunity for people with limited physical space or who need help participating in a larger environment [21].

3. Method

This chapter explains the methodology used throughout the project, which consists of a combined theoretical and practical approach. The first subsection (3.1) will describe the method followed for the pre-study, which informed section 2, where the information required to fully understand the keywords included in the research questions is documented. Subsequent units will cover the research process for the case study (3.2), the design of the case study (3.3), and the feedback collection process (3.4).

The main contribution of this paper is practical, with the overall process divided into six phases: pre-study (which includes Problem Definition and Defining Requirements), Solution Development, Feedback Collection, and Result/Final Prototype. The overall process resembles the reference System Design Processes found in the NASA Systems Engineering Handbook [26] and is visualized in Figure 1 below.

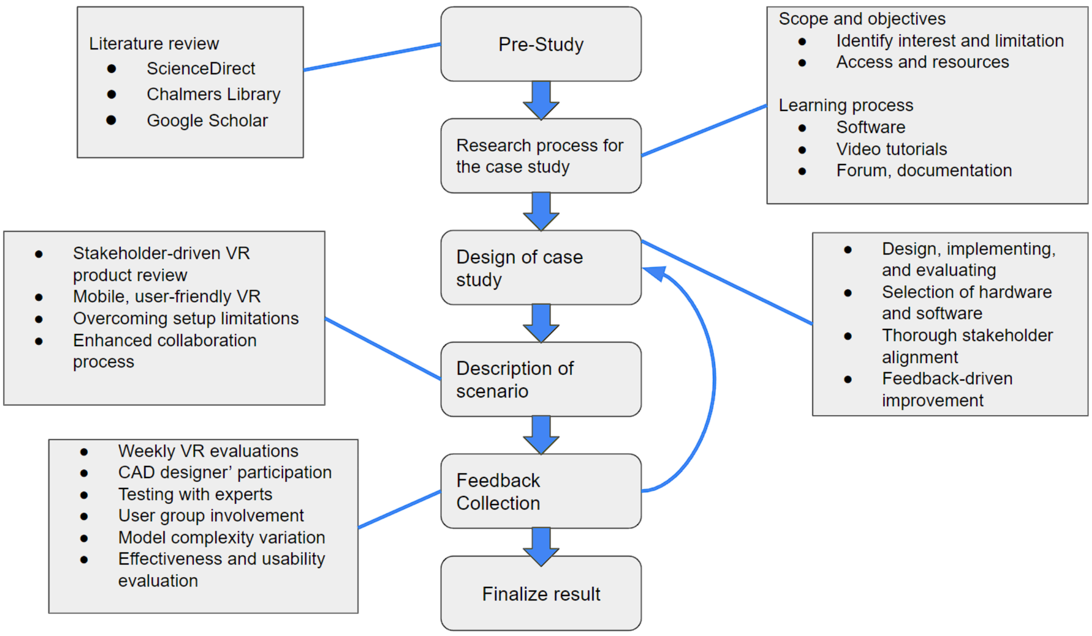

Figure 1: Process Visualization

3.1 Pre-Study

In order to establish a strong foundation for the project, an extensive exploration of various aspects of virtual reality is essential. This includes the history of virtual reality, its applications, benefits, and associated challenges. Google Scholar, ScienceDirect, and the Chalmers Library websites were used to find technical reports, articles, and journals. In order to find relevant material for the project, a keyword planner was created by following the search and evaluation guidelines from Chalmers Library [12]. Examples of keywords include virtual reality, industry 4.0, VR implementation, virtual manufacturing, production, and development. The key was then divided into keyword groups, each consisting of a primary keyword and complementary keywords. The main keyword was complemented and combined according to a boolean search with the AND, OR, and NOT operators. The preliminary study's conclusions were provided in section 2, which focused on theoretical foundations.

3.2 Research process for the case study

To initiate the research at Virtual Manufacturing, a preliminary meeting with the project supervisor was conducted to establish the project's scope and objectives. This involved identifying what the stakeholders at Virtual Manufacturing expected from the project and establishing the limitations. This also included requiring necessary access to different software and resources that were going to be required in order to conduct the study.

Subsequently, we engaged in a comprehensive learning process to familiarize ourselves with the different software utilized throughout the project, which in this case were Unity and Unreal Engines. This involved gathering and studying information from various resources, including reading software documentation, watching video tutorials on platforms such as YouTube, and reading forum threads to gain insights into the different software options' structure, functionality, and capabilities.

3.3 Design of case study

The following chapter describes the development and testing process of designing, implementing, and evaluating the virtual reality (VR) environment with the research described previously in the methodology chapter as a foundation. The chapter outlines the scenario faced, the selection process of appropriate hardware and software, and the execution of rigorous testing to ensure that the VR workspace aligns with the project's objective and the stakeholders' requirements.

3.3.1 Description of scenario

In this scenario, the design team, a key stakeholder in the project, seeks to review their CAD products in a virtual reality (VR) environment before proceeding to the manufacturing stage. The primary objective is to make the review process as simple and convenient as feasible.

The previous solution involved a stationary setup comprising a computer, motion captures, and a VR headset tethered by a long cord. This setup had limitations in mobility and flexibility, which hindered the design team's ability to review products at various locations, such as different areas within the office or at a customer's site.

To address these challenges, the new VR workspace must offer increased mobility and ease of use, enabling the design team to conduct product reviews effortlessly, regardless of location. This enhanced capability will facilitate more efficient collaboration between team members and customers, leading to a more effective product development process.

We will explore various hardware and software configurations to achieve mobility and ease of use. The efficacy of the suggested solutions will be assessed through regular VR reviews, followed by surveying with the design team to gather feedback on potential areas for further enhancement.

3.4 Feedback Collection

We conducted a series of tests with the design team to evaluate the effectiveness and usability of the developed VR environment. We carried out weekly VR reviews with between 1 and 4 CAD designers and experts from the company (depending on availability). Their participation was vital at this stage because they are the main user group that will benefit from developing the prototype proposed in this project. During these sessions, the design team provided us with different models they wanted to review, varying in complexity and number, to establish the limitations of the environment and setup time. A survey was used to gather feedback from the team members participating in the testing phase. The survey consisted of the following questions:

- What is your role within the company?
- How much previous experience do you have with VR technology 1-5
- What benefits would VR add to your standard workflow?
- Did VR make it easier or harder to identify problems with the CAD model compared to the current way of reviewing it inside the CAD software?
- How would you rate the frame rate of the VR experience from 1-5?
- How would you rate the visual quality of the VR experience 1-5?
- How difficult did you feel it was to use the VR technology, get into the environment, and understand the controllers on a scale of 1-5?
- Are there any tools or functionality that would further improve the VR environment?
- Are there any improvements that would enhance the usability of VR as a tool?

The survey aimed to gather insights into the participants' experience with the VR environment and its potential impact on their workflow. The feedback obtained from the survey will be instrumental in identifying areas for improvement and refining the VR application to meet the design team's needs better.

4. Results

In the Results chapter, we present the outcomes of implementing the methodologies discussed in the previous chapter. By collaborating with the design team at Virtual Manufacturing, we developed and tested a VR workspace tailored to their needs. The chapter provides an overview of the findings gathered from the feedback survey completed by team members involved in the testing phase.

The chapter begins with section pre-study (4.1), which outlines the objectives and background information collected during the initial research phase. This information played a crucial role in shaping the development and testing of the VR workspace. The Research Process for the Case Study (4.2) explains the different hardware and software choices and clarifies the rationale behind the decisions made throughout. The Design of the Case Study (4.3) section demonstrates the creation of the VR environment. It highlights the optimization and customization steps taken to meet the design team's specific needs. Finally, the Feedback Collection (4.4) section presents an analysis of the performance evaluation and user feedback. This analysis identifies the potential benefits and limitations of incorporating VR technology into the production design process.

4.1 Pre-Study

The pre-study served as a foundation for the project by gathering background information and establishing objectives. This phase aimed to understand better the current state of the product design process at Virtual Manufacturing. Identifying potential applications, benefits, and limitations of VR technology played a crucial role in implementing VR as a tool in the design process.
The objectives that were identified during the pre-study were:

- To get a thorough grasp of Virtual Manufacturing's current design process.
- To explore the potential benefits and challenges of integrating VR technology into the production design process.
- Determine the hardware and software requirements for building a VR workplace customized to the demands of the design team.
- To develop a VR environment that allows the design team to review and interact with CAD models effectively and efficiently.

- To assess the usability, performance, and overall effectiveness of the developed VR workspace through user feedback and evaluation.

During this phase, we collected background information on the design team's existing workflow, including the CAD software and hardware they employed. We found that the team primarily used IronCAD to design virtual products and relied on STP file formats to export their models. The team desired a more immersive and interactive environment for reviewing their designs, which could be achieved through VR technology.

The literature review conducted during the pre-study phase revealed that the use of VR in product design has been steadily increasing, with numerous advantages such as improved collaboration, enhanced visualization, and more accurate ergonomic assessment [3]. The literature also highlighted potential limitations and challenges, including motion sickness [15, 16], hardware and software compatibility issues, the learning curve associated with new technologies, and the need for ongoing support and updates.

This information guided the hardware and software selection, development processes, and overall VR workspace design and testing. The project intended to construct a VR environment that may boost their product design process while resolving the highlighted obstacles and constraints by knowing the individual needs and preferences of the design team.

4.2 Research Process for the case study

This part of the study unravels the systematic steps followed during the research process. Initially, in section (4.2.1), we focus on the evaluation of the hardware options available, highlighting the selection criteria and the final choice. Moving forward to section (4.2.2), we discuss the software selection process, considering both the Unreal Engine and Unity, detailing the reasons behind our final decision. Lastly, section (4.2.3) delves into the specifics of Unreal Engine development for the Android platform, outlining the necessary tools and steps required for VR application development.

4.2.1 Hardware

The hardware options available for this project were limited to the existing equipment at Virtual Manufacturing. In order to determine the most suitable hardware configuration for the new VR workspace, we carefully assessed the available options, which included the following devices:

- HTC Vive Pro 2 Full Kit
- Oculus Quest 1
- Oculus Quest 2
- Oculus Rift S

A VR-capable computer was also available, featuring an Nvidia GTX 1080 GPU, an Intel i7 7700K CPU, and a hard drive with limited storage space that required cleaning up.

To select the best hardware solution, we compared the specifications and capabilities of each device, as well as their compatibility with the existing computer. The HTC Vive Pro 2 Full Kit offers a high-resolution display and a wide field of view, making it suitable for detailed product reviews. However, it requires a wired connection to the computer, which limits mobility.

On the other hand, the Oculus Quest 1 and 2 are standalone VR headsets that do not require a connection to a computer. They offer greater mobility, but their performance and graphics quality might need to be on par with the HTC Vive Pro 2 or the Oculus Rift S. The Oculus Rift S, while delivering good graphics and performance, also requires a wired connection to the computer.

After considering the pros and cons of each device, we opted for the Oculus Quest 2 due to its standalone capabilities, which provided the desired mobility for the design team. Its performance and graphics capabilities were deemed sufficient to review CAD products in VR. To address the storage limitations of the existing computer, we cleaned up the hard drive by removing unnecessary files and applications, ensuring enough space for the VR workspace software and CAD product files. According to the Oculus documentation, interactive applications must target a minimum of 72 frames per second [27] and will be set as the performance targets for evaluation during testing.

4.2.2 Software

The software used for this project was readily available at the company and relatively familiar to the employees. The primary programs considered were Unreal Engine and Unity, offering free student licenses and enabling work without paying for licenses.

Another relevant software is IronCAD, employed by the design team to create virtual products. In this project, IronCAD was not directly used for development, but existing components designed in IronCAD were utilized to create environments for the game engines.

When focusing on an interactive experience with simpler graphics, Unity is the preferred option. The software boasts user-friendly interfaces and a variety of XR plugin packages and assets, which streamline and simplify development. However, it has its challenges. Unity does not support STP files, commonly used by the design team to export their models. Consequently, additional software, such as Fusion 360 or Pixyz, is needed to export compatible file formats for Unity.

In contrast, Unreal Engine offers high-quality, photorealistic graphics with advanced lighting and rendering capabilities, making it a popular choice among game developers. However, its interface could be more user-friendly than Unity's; Unreal Engine also provides a range of packages and assets for download. A significant advantage of Unreal Engine is its ability to directly import STP files, reducing the steps involved in the process. Moreover, the engine includes a feature called "blueprints," a visual scripting system that allows developers with no coding background to create game structures and components.

After evaluating both engines side by side, Unreal Engine emerged as the superior option and was selected for the company. Although Unity does have a more user-friendly interface, it requires some knowledge of coding in C# or C++, which can be challenging to learn. While coding knowledge is also necessary for Unreal Engine, the blueprints feature is sufficient for this project.

4.2.3 Unreal Engine Development for the Android Platform

The development of a virtual reality experience in Unreal Engine for the Android platform requires specific preliminary requirements and tools to be met and installed. This ensures compatibility and optimal performance for the target device, such as the Oculus Quest. This section will discuss the necessary components and steps for Unreal Engine development targeted for the Android platform.

Before initiating the development process for the VR application, it is crucial to install and configure the required components for VR development on the Android platform.

Android Studio plays an integral role in the project as an integrated development environment (IDE) for creating VR applications on the Android platform, specifically targeting the Oculus Quest. Developed and maintained by Google, Android Studio offers a comprehensive set of tools for creating, testing, and deploying Android applications [22]. It is important to note that Android Studio is necessary for seamless compatibility with Unreal Engine, as it helps developers harness the powerful capabilities of both platforms. Essential components for the development process include the following:

Android SDK: This set of tools and libraries is required to build and test Android platform applications. It comprises platform-specific components such as build tools, API libraries, and system images for various Android versions [23].

Android NDK: The NDK allows developers to utilize native code (C and C++) in their Android applications, ensuring better performance and easier integration with native libraries for specific Android devices [24].

JDK: The Java Development Kit, a collection of tools and libraries for developing Java applications, is a prerequisite for Android Studio since Android applications are predominantly built using Java [25].

These components are vital for various aspects of Android application development, such as compiling, debugging, and packaging the application.

Once Android Studio is installed and configured, it facilitates the packaging and distribution of applications by enabling developers to create APK files, which can be installed and run on Android devices. In summary, Android Studio is an indispensable component of the development process for creating VR applications in Unreal Engine aimed at the Android platform. It offers a range of tools and features that streamline the workflow, enhance code quality, and guarantee compatibility and performance on target devices.

4.3 Design of the case study

Unreal Engine has a built-in VR template, shown below in Figure 2. The template provides a pre-configured VR project setup, including essential features like motion controller support and teleportation functionality. This pre-built template saved time and effort and allowed more time to be focused on customizing and optimizing the application for the specific use case.

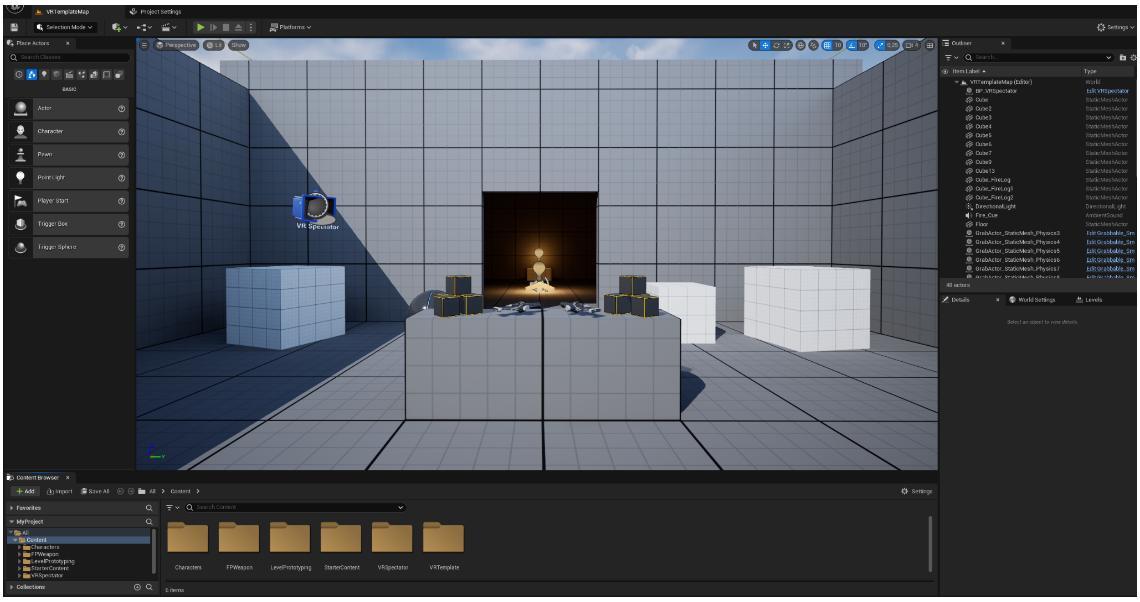

Figure 2: VR template inside the Unreal Engine Editor

The design team provided CAD files in the STP file format that were imported into Unreal Engine using Datasmith. Datasmith is a powerful and flexible data translation and optimization tool that can be installed in Unreal Engine. Datasmith enables the import of complex 3D models and scenes from various CAD software and file formats that are not naturally supported directly in Unreal Engine.

The imported CAD files were further optimized using DataPrep, shown in Figure 3, a data preparation tool built into Unreal Engine. DataPrep enables developers to define a series of optimization operations to clean up, simplify, and optimize imported CAD data. This process ensures the VR application runs smoothly and maintains the desired frame rate.

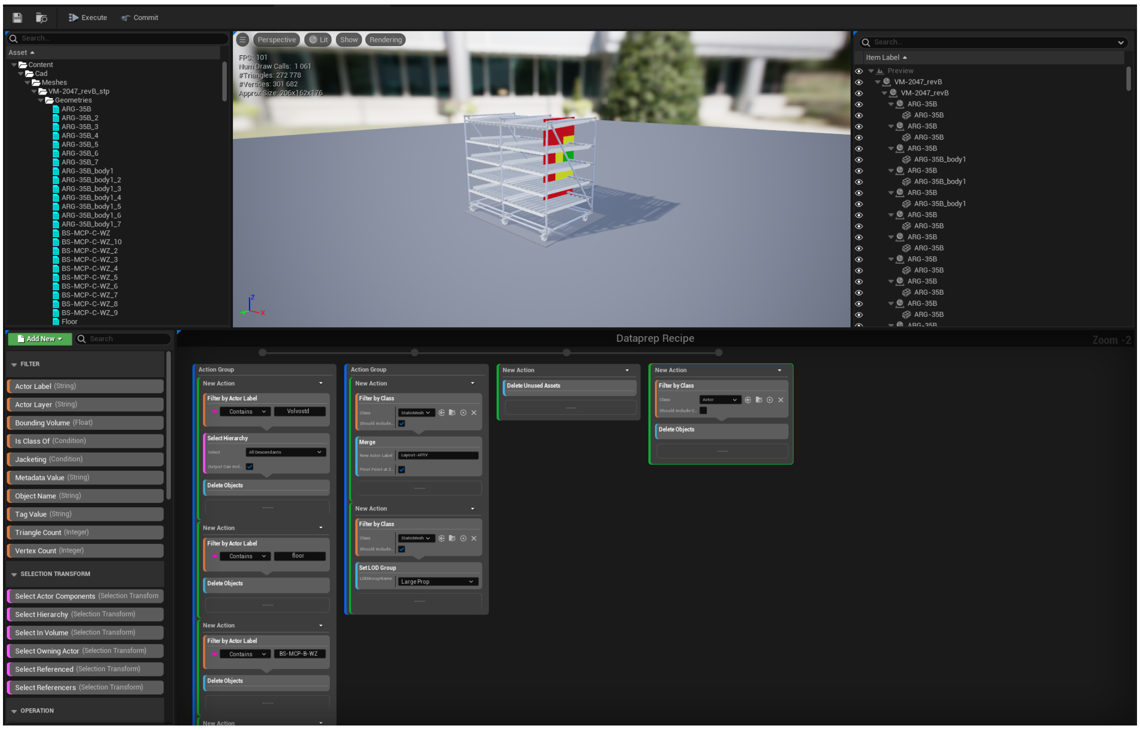

Figure 3: The DataPrep Tool

Creating a visually appealing and functional environment is essential for a successful VR application. The environment design process began with defining the overall layout and aesthetics of the space, considering factors such as scale, lighting, and material choices to create an immersive and visually appealing setting. The environment was designed to complement the imported CAD models, providing a proper context for users to review and interact with the products.

To ensure smooth navigation and interaction within the VR environment, the team customized the navigation mesh boundary to fit the specific layout of the environment. The navigation mesh determines the areas where users can move and interact with objects. It is represented by the green area in Figure 4, making it essential to configure it accurately to provide a seamless and intuitive user experience.

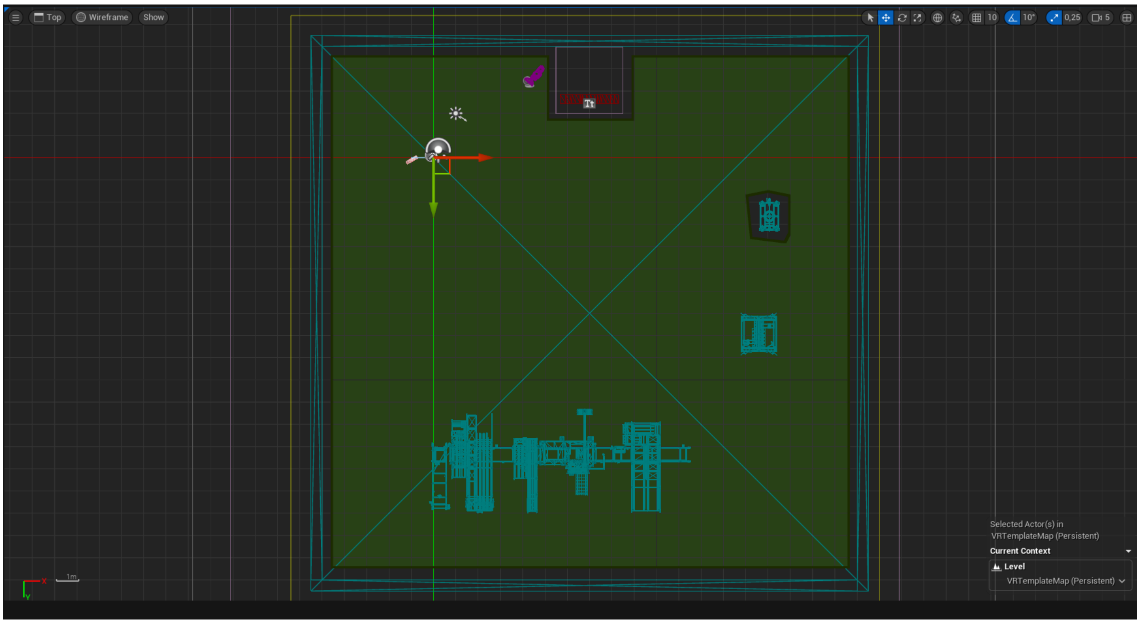

Figure 4: Navigational Mesh Boundary

Lighting plays a crucial role in creating a realistic and immersive VR experience. The team carefully considered the lighting setup, considering factors such as light sources, shadows, and color temperature. In VR applications, performance optimization is of utmost importance, and the choice of lighting can significantly impact performance. Real-time dynamic lighting can be resource-intensive, by choosing static lighting in combination with using lightmaps and baked lighting to achieve a visually appealing environment while maintaining the desired frame rate. The chosen lighting is visualized below in Figure 5.

Figure 5: Lightning visualization

4.4 Feedback Collection

The performance evaluation examines the VR environment's frame rate and visual quality, as these aspects significantly impact the user experience. Achieving a reasonable frame rate ensures a smooth VR experience, while the visual quality has implications for both realism and the accurate representation of CAD models.

In order to performance test the VR environments frame rate, the console command "StartFPSChart" was used in the unreal engine editor. This logs every single frame and then calculates the average FPS. The frame rate achieved during one of the tests is shown in Figure 6.

```
--- Begin : FPS chart dump for level 'VRTemplateMap'
Dumping FPS chart at 2023.04.28-13.12.22 using build ++UE5+Release-5.1-CL-23901901 in config Development built from changelist 23901901
Machine info:
        OS: Windows 10 (21H2) [10.0.19044.2846]
        CPU: GenuineIntel Intel(R) Core(TM) i7-6700 CPU @ 3.40GHz
        DeviceProfile: WindowsEditor
        GPU: NVIDIA GeForce GTX 1080 (desktop adapter DisplayLink USB Device)
        Resolution Quality: 100.00
        View Distance Quality: 3
        Anti-Aliasing Quality: 3
        Shadow Quality: 3
        Global Illumination Quality: 3
        Reflection Quality: 3
        Post-Process Quality: 3
        Texture Quality: 3
        Effects Quality: 3
        Foliage Quality: 3
        Hair Quality: 3
        Window Mode: WindowedFullscreen
        Resolution: 1920x1200
43804 frames collected over 388.43 seconds, disregarding 0.00 seconds (0 frames) for a 112.77 FPS average
Average GPU frametime: 8.77 ms
```

Figure 6: Performance Test

During several performance tests, the frame rate successfully met the desired target of 72 fps, described in Chapter (4.2.1), ensuring a smooth and comfortable VR experience. User feedback gathered through surveys and interviews provided invaluable insights into the VR environment's visual quality, usability, and potential enhancements. The design team's perspectives have been critical in identifying areas needing further development.

The design team rated the visual quality of the VR environment 3 out of 5. They found the overall lighting and realism adequate but expressed a desire for improvements in texture quality if the hardware could support it. While some environmental details enhanced the overall realism, the main goal was to display the CAD models as accurately as possible.

The design team found the user controllers inside the VR environment easy to use and understand, rating its usability 4 out of 5. However, they suggested an alternative joystick-based navigation system similar to those found in most video games to improve the overall user experience.

The design team provided valuable insights when comparing the VR environment to their current CAD software review process. They highlighted the benefits and limitations of VR technology for model review, allowing for a more balanced understanding of how the two methods can complement each other in a design workflow.

Regarding enhancements, the team mentioned that they could envision VR technology being particularly useful in checking ergonomics and getting a more realistic perspective of the model during the design process. By using VR, designers can better visualize and interact with the models, making it easier to assess the feasibility of their designs from an ergonomic standpoint.

On the other hand, when asked to compare the ease of identifying issues with CAD models in the VR environment versus their CAD software, the team found that it was easier to identify realistic-level issues during ergonomic tests in VR. However, they also pointed out that VR had limitations in revealing finer details due to graphic constraints. This suggests that while VR offers advantages in assessing ergonomics and overall design feasibility, CAD software may still be the preferred choice for evaluating detailed design aspects.
Based on the user feedback, the following improvements were proposed:

Enhancements in texture quality, if permitted, to provide a more accurate representation of CAD models.
Alternative navigation options, such as joystick-based movement, provide the users with more familiar navigation options to improve usability.
Modifications to the navigational boundary allow users to step onto platforms, enabling the evaluation of ergonomics at different heights and improving the overall testing experience.

5. Discussion

In this chapter, the findings from the previous chapters are discussed, focusing on answering the research questions posed at the beginning of the study.

RQ.1 *What are the technical requirements in order to implement a reusable virtual reality workspace to be used in production development projects ?*

The process of implementing a reusable virtual reality workspace was explored throughout the study, involving various factors such as hardware, software, optimization, and customization. While several different hardware and software options have the potential for a wide array of VR applications, several were not covered in this thesis.
The selection of the Oculus Quest 2 as the most suitable hardware option from the available hardware provided the mobility and performance required to review CAD models in VR [8].

The choice of Unreal Engine as the software platform enabled the option to pack the environment as an APK file, which could be run directly on the headset without using a computer or an internet connection. While several other software options also can create VR environments, Unreal Engine provides thorough software documentation, free tools, and assets while simultaneously being a familiar software at the company and enabling standalone VR.

The importance of careful consideration and evaluation of the available options in terms of hardware and software, as well as continuous optimization and customization to ensure the VR workspace remains relevant and practical, are critical requirements to implement a reusable virtual reality workspace.

RQ.2 *What are the benefits of having VR as a tool in production development projects, and what does it add to Virtual Manufacturing and their customers?*

The team's feedback after testing and evaluation has been positive overall. The VR workspace has helped the team identify problems at a realistic level during ergonomic tests. However, there is room for improvement and further development, such as improving graphics quality to detect errors at a detailed level and providing alternative joystick-based navigation in the environment for increased user-friendliness.

Previous research has shown that VR within Industry 4.0 provides endless benefits, including optimizing business activities and developing training programs for military operations and other medical exercises [3]. Another advantage of using VR is that it helps developers improve the use of Digital Twins to create virtual objects or production environments, enabling better analysis of potential hazards or errors that might occur. As a result, businesses and organizations save money and time [4].

RQ.3 *How can the threshold to use virtual reality in production development projects be lowered and more easily used?*

The project highlighted the need for user-friendly interfaces, efficient navigation, and easy-to-understand controllers to make VR more accessible for users[28]. By addressing these factors, the VR workspace can be integrated into the workflow with minimal disruption, allowing for a smoother transition to the new technology and enabling the design team to harness the full potential of VR in their projects. Acknowledging the importance of understanding the user experience and adapting the VR workspace to meet the needs for its specific application are key factors in order to lower the threshold for VR adoption and ensure its successful integration into the production development process.

The method used throughout the project is limited because it relies on the feedback and evaluation of a small group of users. Despite the importance of gathering feedback from the primary uses of the VR environment, the results may only partially represent the perspectives and requirements of other stakeholders involved in the manufacturing process. There may be different perspectives about the usability, benefits, and potential improvements of VR environments among individuals from different departments within the company or customer.

In order to overcome this limitation, it would be beneficial if representatives of other departments or user groups were included in the feedback collection process. It may involve individuals in manufacturing, quality control, or even end users who interact with the final product. It is possible to provide a greater understanding of the impact and effectiveness of the VR environment across different stakeholders by incorporating a broader range of perspectives in evaluation. It is also possible to uncover new insights and identify additional areas for improvement by involving a diverse set of users that might have yet to be considered by the design team alone when involving a diverse set of users.

6. Conclusion

VR has the potential to enhance the production development process for both Virtual Manufacturing and other companies by enabling them to review and evaluate the feasibility of the models and identify problems at a realistic level during ergonomic tests. Therefore, this project aimed to determine the technical requirements, benefits, and limitations of implementing a virtual reality workspace that can be used as a tool in production development projects. Reflecting on the project's journey, the findings have confirmed VR's significant potential for enhancing production development processes and Virtual Manufacturing.

The requirements for implementing a reusable VR workspace were addressed during the study. The study showed the importance of careful consideration and evaluation of the available options in terms of hardware and software to fit the needs of the targeted application, as well as continuous optimization and customization to ensure the VR workspace remains relevant and practical, which are key requirements in order to implement a reusable virtual reality workspace.

Furthermore, the study revealed that the threshold for VR adoption in production development projects could be lowered by focusing on user experience, developing user-friendly interfaces, and ensuring the controllers and navigation are intuitive and efficient.

Recommendations for future work include a long-term evaluation of the impacts of VR adoption on production development projects and exploring the potential for further optimization and customization of the VR workspace.

In conclusion, this study has highlighted the potential of VR as a tool for production development projects, providing valuable insights into the requirements for its implementation, the benefits it offers, and ways to make it more accessible. These discoveries lay the groundwork for future research and development in this field, potentially revolutionizing the production development process for Virtual Manufacturing and other similar enterprises.

References

[1] Kampker A, Wessel S, Lutz N, Bildhauer M, Hehl M. Holistic integration of a VR solution into the planning process of scalable production systems. Procedia CIRP. 2020;88:133–8.

[2] Frank AG, Dalenogare LS, Ayala NF. Industry 4.0 technologies: Implementation patterns in manufacturing companies. International Journal of Production Economics. 2019 Apr;210(210):15–26.

[3] Lorenzo Damiani, Melissa Demartini, Guido Guizzi, Roberto Revetria, Flavio Tonelli, Augmented and virtual reality applications in industrial systems: A qualitative review towards the industry 4.0 era, IFAC-PapersOnLine, Volume 51, Issue 11, 2018.

[4] Jensen L, Konradsen F. A review of the use of virtual reality head-mounted displays in education and training. Education and Information Technologies. 2017 Nov 25;23(4):1515–29.

[5] M Eswaran, M V A Raju Bahubalendruni, Challenges and opportunities on AR/VR technologies for manufacturing systems in the context of industry 4.0: A state of the art review, Journal of Manufacturing Systems, Volume 65, 2022, Pages 260-278,
ISSN 0278-6125,

[6] Treviño-Elizondo BL, García-Reyes H. What does Industry 4.0 mean to Industrial Engineering Education? Procedia Computer Science. 2023;217:876–85.

[7]Unity Technologies. Architecture, Engineering & Construction | Unity [Internet]. Unity. 2020. Available from:
https://unity.com/solutions/architecture-engineering-construction

[8] Kress BC, Starner T. A review of head-mounted displays (HMD) technologies and applications for consumer electronics. 2013 May 31;

[9] Chen C. Immersive virtual reality to train preservice teachers in managing students' challenging behaviours: A pilot study. British Journal of Educational Technology. 2022 Jan 9;

[10]Projection VR - WorldViz VR [Internet]. www.worldviz.com. Available from: https://www.worldviz.com/projection-vr

[11] Will it Run? VR Hardware Requirements for your PC or Laptop [Internet]. circuitstream.com. Available from: https://circuitstream.com/blog/vr-hardware

[12] Nordfeldt L. LibGuides: Söka och utvärdera information: Sökteknik [Internet]. guides.lib.chalmers.se. [cited 2023 May 23]. Available from: https://guides.lib.chalmers.se/sokaochutvarderainformation/sokteknik

[13] Barnard D. History of VR - Timeline of Events and Tech Development [Internet]. Virtualspeech.com. VirtualSpeech; 2019. Available from: https://virtualspeech.com/blog/history-of-vr

[14] Ifanov, Jessica P, Salim S, Syahputra ME, Suri PA. A Systematic literature review on implementation of virtual reality for learning. Procedia Computer Science [Internet]. 2023 Jan 1 [cited 2023 Jan 16];216:260–5. Available from: https://www.sciencedirect.com/science/article/pii/S187705092202213X

[15] Simón-Vicente L, Rodríguez-Cano S, Delgado-Benito V, Ausín-Villaverde V, Cubo Delgado E. Cybersickness. A systematic literature review of adverse effects related to virtual reality. Neurología [Internet]. 2022 Jul 8 [cited 2022 Nov 27]; Available from: https://www.sciencedirect.com/science/article/pii/S0213485322000664#:~:text=They%20found%20that%2045%25%20of

[16] Matthews R. Are VR headsets bad for your health? [Internet]. BBC Science Focus Magazine. BBC Science Focus Magazine; 2019. Available from: https://www.sciencefocus.com/future-technology/are-vr-headsets-bad-for-your-health/

[17] Static Meshes [Internet]. docs.unrealengine.com. [cited 2023 May 23]. Available from: https://docs.unrealengine.com/4.26/en-US/WorkingWithContent/Types/StaticMeshes/

[18] Millington I. Springs and Spring-Like Things. 2010 Jan 1;89–111.

[19] Blueprints Visual Scripting [Internet]. docs.unrealengine.com. Available from: https://docs.unrealengine.com/5.1/en-US/blueprints-visual-scripting-in-unreal-engine/

[20] Technologies U. Unity Visual Scripting | Unity [Internet]. unity.com. Available from: https://unity.com/features/unity-visual-scripting

[21]VR Locomotion Design Guide | Oculus Developers [Internet]. developer.oculus.com. Available from: https://developer.oculus.com/resources/bp-locomotion/

[22] Google Developers. Meet Android Studio | Android Developers [Internet]. Android Developers. 2019. Available from: https://developer.android.com/studio/intro

[23] Command-line tools | Android Studio [Internet]. Android Developers. [cited 2023 May 23]. Available from: https://developer.android.com/tools

[24] Android NDK [Internet]. Android Developers. Available from: https://developer.android.com/ndk

[25] JDK 20 documentation - home. Oracle Help Center. (2023, April 18). https://docs.oracle.com/en/java/javase/20/index.html

[26] Shea G. NASA Systems Engineering Handbook Revision 2 [Internet]. NASA. 2017. Available from: https://www.nasa.gov/connect/ebooks/nasa-systems-engineering-handbook

[27] Oculus Quest: Testing and Performance Analysis | Oculus Developers [Internet]. developer.oculus.com. [cited 2023 May 23]. Available from: https://developer.oculus.com/documentation/unreal/unreal-debug-android/

[28] Phoebe. Unreal Engine vs. Unity 3D: Which Engine is Best Choice for Your Game? | Unreal Engine Cloud Rendering [Internet]. iRender Cloud Rendering Service. 2022. Available from: https://irendering.net/unreal-engine-vs-unity-3d-which-engine-is-best-choice-for-your-game/

[29] Unreal Engine: the open automotive platform and data model of the future [Internet]. Unreal Engine. [cited 2023 Jun 8]. Available from: https://www.unrealengine.com/en-US/spotlights/unreal-engine-the-open-automotive-platform-and-data-model-of-the-future

[30] Technologies U. Immersive Training Powered by Unity | AR & VR Solutions [Internet]. unity.com. [cited 2023 Jun 8]. Available from: https://unity.com/solutions/immersive-training

[31] VR Performance Features [Internet]. docs.unrealengine.com. Available from: https://docs.unrealengine.com/4.26/en-US/SharingAndReleasing/XRDevelopment/VR/DevelopVR/VRPerformance/

Appendix

Responses cannot be edited

Vr-review feedback

We want to know what you think and what can be improve!

1. What is your role within the company?

Design Engineer and Product Developer

2. On a scale of 1-5, how familiar are you with VR technology? (1 being the least familiar and 5 being the most familiar)

1	2	3	4	5
○	○	◉	○	○

3. How do you envision VR technology enhancing your standard workflow?

Checking Ergonomics and measurements during Concept-phases

4. Comparing VR to your current CAD software review process, did you find it easier or harder to identify issues with the CAD model in the VR environment?

Easier on a realistic level during ergonomic tests, harder on details because of graphic limitations in VR-environments

5. On a scale of 1-5, how would you rate the frame rate of the VR experience? (1 being very poor and 5 being excellent)

1	2	3	4	5
○	○	○	○	◉

6. On a scale of 1-5, how would you rate the visual quality of the VR experience? (1 being very poor and 5 being excellent)

1	2	3	4	5
○	○	◉	○	○

7. On a scale of 1-5, how easy was it for you to use the VR technology, navigate the environment, and understand the controllers? (1 being very difficult and 5 being very easy)

1	2	3	4	5
○	○	○	◉	○

8. Can you suggest any additional tools or functionality that would improve the VR environment for CAD model review?

If possible, try to have some better graphic option(If we have better hardware aswell)

8. Can you suggest any additional tools or functionality that would improve the VR environment for CAD model review?

If possible, try to have some better graphic option(If we have better hardware aswell)

9. Are there any specific improvements or changes that could enhance the usability of VR as a tool for your workflow?

an option of navigating with Joysticks, similar to a FPS game

10. Do you think the VR environment could help streamline the design review process and reduce the overall time spent on product development?

Yes, in regards of checking ergonomic and measurments, it could be better for a smoother process in projects

Is there anything else you would like to add or suggest for our VR-review development project?

CHALMERS