FACULDADE DE ENGENHARIA DA UNIVERSIDADE DO PORTO

# VRTraining 3D Authoring Tool for Industrial Training using Virtual Choreographies

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# Abstract

Virtual Reality (VR) is a powerful tool for industrial training due to its capacity to simulate realistic, risk-free environments. However, creating VR training scenarios often requires significant technical expertise and large investments, limiting the technology's adoption. The role of professional trainers in this process is also often overlooked. This work addresses these issues by investigating three different research questions that dive deeper into what features a VR training platform needs to have, how it can take advantage of Virtual Choreographies, and how trainers can be involved in the training and creation process. To complement and validate this research, a prototype VR training and authoring tool is also presented, which incorporates the features researched. This platform empowers trainers to author, test, and deliver immersive training procedures directly within a VR environment without writing code. It also gives trainees a place to practice and learn without consequences. A key feature is the integration of *Virtual Choreographies*, enabling trainers to define ordered procedures, record trainee attempts, more easily understand their actions, and automatically assess performance. To validate the prototype, a user study was conducted where the usability, workflow clarity, and feature effectiveness were evaluated. Results indicate strong usability and comprehension for non-expert users, and confirm the potential of *Virtual Choreographies* to guide and evaluate procedural training. This work represents a step toward creating accessible, customizable VR training for industrial and educational settings.

# Resumo

A Realidade Virtual (RV) é uma ferramenta poderosa para a formação industrial devido à sua capacidade de simular ambientes realistas e sem riscos. No entanto, a criação de cenários de formação em RV requer frequentemente conhecimentos técnicos significativos e grandes investimentos, o que limita a adoção da tecnologia. O papel dos formadores profissionais neste processo também é frequentemente ignorado. Este trabalho aborda estes problemas, investigando três diferentes questões que aprofundam o conhecimento de quais as características que uma plataforma de formação em RV deve ter, como pode tirar partido de *Coreografias Virtuais* e como os formadores profissionais podem estar envolvidos no processo de formação e na criação de experiências de treino. Para complementar e validar esta investigação, é também apresentada uma ferramenta protótipo de formação e criação em RV, que incorpora as características investigadas. Esta plataforma permite aos formadores criar, testar e administrar procedimentos de formação imersivos diretamente num ambiente de RV sem a necessidade de escrever código. Também proporciona aos formandos um local para praticar e aprender sem consequências. Uma característica fundamental é a integração de *Coreografias virtuais*, o que permite aos formadores definir procedimentos ordenados, registar as tentativas dos formandos, compreender as suas ações mais facilmente e avaliar automaticamente o seu desempenho. Para validar o protótipo, foi realizado um estudo com utilizadores, no qual foram avaliadas a usabilidade, a clareza do fluxo de trabalho e a eficácia dos recursos. Os resultados indicam forte usabilidade e compreensão para utilizadores não especializados e confirmam o potencial das *Coreografias Virtuais* para orientar e avaliar o treino de procedimentos industriais. Este trabalho representa um passo em direção à criação de experiências de treino em RV de uma forma acessível e personalizável para ambientes industriais e educacionais.

# UN Sustainable Development Goals

The United Nations Sustainable Development Goals (SDGs) provide a global framework to achieve a better and more sustainable future for all. They include 17 goals that address the world's most pressing challenges, including poverty, inequality, climate change, environmental degradation, peace, and justice.

The *VR Training and Authoring Tool* developed in this dissertation contributes directly to several of these goals by enabling inclusive, safe, and effective training in industrial and educational settings. It empowers trainers to create and deliver immersive VR-based training scenarios without needing programming skills, which reduces technical barriers and promotes sustainable skill development.

The specific Sustainable Development Goals addressed in this work include:

**SDG 4:** Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all.

**SDG 7:** Ensure access to affordable, reliable, sustainable, and modern energy for all.

**SDG 8:** Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all.

**SDG 9:** Build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation.

| SDG | Target | Contribution | Performance Indicators and Metrics |
|---|---|---|---|
| 4 | 4.3 | Increases access to vocational and technical training through immersive and customizable virtual learning environments. | Number of unique training scenarios authored by non-technical educators; trainee diversity metrics. |
| | 4.4 | Strengthens practical and technical skills by allowing safe repetition and feedback through *Virtual Choreographies*. | Measured improvements in task performance and retention; skill transfer assessment in real-world tasks. |
| 7 | 7.1 | Enables trainers to simulate procedures in VR for safer and more efficient solar plant maintenance, increasing the reliability of clean energy systems. | Number of procedures virtualized; error rate reduction in solar energy maintenance simulations. |
| | 7.2 | Facilitates development of renewable energy-related training, supporting broader adoption and understanding of sustainable energy technologies. | Growth in training scenarios related to renewable energy; trainee satisfaction and learning outcome ratings. |
| 8 | 8.1 | Provides customizable tools for training and upskilling, improving productivity and employment opportunities in industrial sectors. | Number of trainees certified using the platform; productivity metrics in real-world transfer scenarios. |
| | 8.2 | Supports technological upgrading by integrating immersive digital tools into education and vocational training systems. | Integration with industry training pipelines; feedback from trainers on platform usability. |
| 9 | 9.1 | Contributes to the digital infrastructure for training in industrial contexts, enhancing access and innovation. | Number of institutions adopting the tool; technical integration with other platforms (e.g., LMS). |
| | 9.5 | Promotes research and innovation in VR-based training by demonstrating a scalable model for industry-relevant learning. | Academic publications, prototype iterations, and evaluation outcomes related to innovation. |

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Aníbal Ferreira

*"I have no special talents. I am only passionately curious."*

Albert Einstein

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# List of Acronyms

| | |
|---|---|
| XR | Extended Reality |
| VR | Virtual Reality |
| AR | Augmented Reality |
| IAP | Inventive Activities Plans |
| HMD | Head Mounted Display |
| KMS | Knowledge Management Strategies |
| SME | Subject Matter Experts |
| DSR | Design Science Research |
| DSRM | Design Science Research Methodology |
| RQ | Research Question |
| SLR | Systematic Literature Review |
| US | User Stories |
| CAD | Computer Aided Design |
| VE | Virtual Environment |
| 3D | Three Dimensions |
| UI | User Interface |
| UX | User Experience |
| POV | Point Of View |
| FR | Functional Requirements |
| NFR | Non-Functional Requirements |
| TR | Technical Requirements |
| ID | Identifier |
| DOF | Degrees Of Freedom |
| ISEMV | IEEE International Symposium on Emerging Metaverse |
| LMS | Learning Management System |
| UN | United Nations |
| SDG | Sustainable Development Goals |

# Chapter 1

# Introduction

This thesis presents the research into Virtual Reality training platforms applied to industrial procedures and how they can be improved in order to increase overall adoption and ensure high training effectiveness. Alongside this, the design, research, development, and evaluation of a prototype Virtual Reality training and authoring platform aimed at industrial education is also presented. The work spans multiple phases, from identifying key requirements through literature reviews and surveys, to iterative prototyping, user testing, final validation, and academic publications. At its core, this work proposes guidelines to be followed when designing a VR training platform to ensure a high-quality training experience, with minimal costs and consequences, as well as proposing a tool that enables trainers to author and deliver high-quality, immersive training experiences without the need for professional developer skills, supported by the integration of *Virtual Choreographies* to enhance feedback and assessment.

The practical work and research presented in this thesis was carried out in close collaboration with INESC TEC. The author was responsible for the research conducted and the development cycle of a prototype VR training platform, including architecture design, system implementation, and usability evaluation. The supervisors provided guidance, technical feedback, and strategic direction throughout the entire work, particularly in defining the research questions, refining the scope, and validating the methodology. User testing was conducted with volunteers who were not part of the development process, ensuring unbiased feedback.

This division of work ensured a well-rounded approach that combines academic rigor, technical innovation, and practical relevance.

## 1.1 Context

Since NASA's early initiatives in the 1990s (Garcia, Schlueter, and Paddock 2020), immersive environments have been an area of interest for education and training. With the rise of advanced platforms like Oculus, Valve, HoloLens, and others, the potential for Virtual Reality (VR) in learning has grown exponentially. This rise has also been fueled by Meta's recent focus on Extended Reality (XR), leading to many innovations in immersive experiences and education. However, like

all endeavors, the search for immersive training has its unique challenges, like the one encountered by the military training game Full Spectrum Warrior, commissioned by the U.S. Army. Despite the initial appeal, it struggled with the fact that, by release, the tactical doctrines it tried to teach were outdated and no longer needed. This showcased a need for VR training platforms to be quickly adaptable and customizable by educators that do not have professional developer skills.

For immersive education to be successful, educators and learners must be able to create and adapt their own immersive content. Rigid, pre-designed training environments are likely to be outdated (Core, Nye, and Fegley 2024). Addressing this issue, INESC TEC has been at the forefront of research into immersive learning technologies. Since 2013, INESC TEC has focused on identifying and overcoming barriers to the widespread adoption of immersive learning, publishing a list of challenges that was later analyzed through a global survey of researchers and professionals. The results, published in the Virtual Reality journal (Gaspar et al. 2020), outlined key areas of focus: accessibility, content development, and integration with organizational systems.

One of the major outcomes of this research has been the development of Inven!RA (Cota et al. 2021), a software architecture for immersive learning. Inven!RA operates as a service-oriented architecture, allowing third-party developers to provide their activities and analytics transparently. With Inven!RA, learning designers can combine several learning activities in an Inventive Activities Plan (IAP) and link their analytics to the overall learning goals. Any teacher or trainer can then deploy the IAP to their students/trainees and track ongoing activities towards goals, be they immersive platforms, Internet-of-Things physical environments, or pervasive gaming with georeferenced smartphones (A. Coelho et al. 2020). Inven!RA was inspired by the BEACONING project, which won several awards and during which INESC TEC developed the architecture and authoring tool (Cardoso, Morgado, and Coelho 2020) that inspired the efforts leading into Inven!RA.

In addition to Inven!RA, INESC TEC also created the concept of *Virtual Choreographies* (Costa 2023; Silva et al. 2012), a breakthrough in how actions are represented and interpreted. Rather than defining actions as coordinates or specific geometric surfaces or assets, Virtual Choreographies define them at a higher semantic level, allowing them to be more easily understood. This concept was demonstrated in the VESTAS wind turbine training system, where it obtained promising results.

While integrating the concept of *Virtual Choreographies*, INESC TEC went on to develop VR-Training (INESC TEC 2021; Fernando Cassola et al. 2021), a training platform that blends Digital Twin and Virtual Reality (VR) technologies to revolutionize training methodologies in industrial environments. It allows educators to create immersive, high-quality VR training courses for complex systems without the need for professional developers (Fernando Cassola et al. 2022). Trainers can design these virtual environments in great detail and define procedural steps for trainees to follow. Virtual Choreographies are used to capture and record user interactions in human-meaningful terms, enabling intuitive training and certification processes (Cassola et al. 2021).

This thesis aims to build on these innovations by attempting to answer some key research questions about how Virtual Reality can be effectively used to support training and assessment in industrial training settings, in collaboration with expert trainers. It explores the pedagogical,

technical, and experiential factors that influence the success of VR-based learning. It also intends to validate the knowledge acquired with a prototype VR training and authoring platform, thus combining theory and practice.

## 1.2 Motivation

The increasing complexity of industrial systems, as well as the high costs of training, leads companies to search for alternatives in the form of virtual environments. Pre-designed programs often struggle with the constant changes in technology and procedures, leading to costly systems that quickly become obsolete (Core, Nye, and Fegley 2024). This raises the need for a customizable training platform that can be tailored to any training scenario and allows employees to be trained in a safe, repeatable, controlled, and affordable environment free of risks (Fernando Cassola et al. 2022).

Such a platform would allow trainers to create high-quality training courses tailored to very specific needs while ensuring this training remains relevant and up-to-date. Alongside this, the integration of *Virtual Choreographies* enables the assessment of trainees in a more intuitive and meaningful way, improving learning outcomes and better preparing professionals for the tasks they will need to complete (Fernando Cassola et al. 2022). This interaction between trainer and trainee would also be paramount to enable trainers to not only educate but also accurately certify candidates on their newly acquired skills.

## 1.3 Problem

This dissertation aims to tackle the problem of what features a virtual training platform needs to have to provide an adequate and up-to-date training while being reliable enough to allow educators to certify trainees. The industry requires a tool that is adaptable to the changes in procedure and advances in technology, that can ensure a high-quality training, and that works with trainers, and not against them, to accurately assess trainees. On top of these qualities, it also needs to be able to keep risks and costs down, meaning it should be user-friendly, and trainers should not require extensive training to operate such a platform and create detailed virtual environments within it. Existing platforms allow users to select and add courses inside the virtual environment, which can increase the complexity of using the system and make it more difficult for users new to VR. Available systems also require the use of game controllers that further steepen the learning curve to those not familiar with them. Lastly, data management is also problematic since it should be easy to export data out of the virtual environment to be evaluated, as well as quickly import training courses developed by others.

## 1.4 Research Questions

From the aforementioned problem, we can draw the following research questions:

**RQ1a:** *What characteristics are necessary in a VR training platform to provide an adequate and up-to-date training?*

**RQ1b:** *What characteristics are necessary in a VR training platform to allow educators to certify trainees?*

**RQ2:** *How can virtual choreographies be incorporated in a VR training platform to help trainers understand user actions and create new courses?*

**RQ3:** *How can a virtual training platform work with professional industrial trainers instead of attempting to replace them?*

## 1.5 Thesis Structure

This thesis is organized into eight chapters, which cover the various steps taken in the research process:

**Introduction:** Presents the context, motivation, and problem statement that led to the development of this work. It outlines the research questions and goals, framing the relevance of virtual reality (VR) training in industrial and educational contexts.

**Literature Review:** Describes the exploratory review and the search for related research, identifying gaps and establishing the foundational concepts of VR training platforms, authoring tools, and *Virtual Choreographies*.

**State Of The Art:** Analyzes the current technologies and approaches in VR-based training while identifying gaps in the literature and future work. It contains a thematic analysis of reviews previously selected that will guide a more complex Systematic Review.

**Adopting a Design Science Research Methodology:** Details the methodological framework used throughout the thesis. It describes the Design Science Research Methodology (DSRM) and explains how it guided the iterative design, development, and evaluation phases.

**Requirements:** Outlines the Systematic Review performed and provides answers to the research questions. From those answers, the functional, non-functional, and technical requirements of the platform, as well as the respective user stories, are defined. It also identifies key stakeholders and system constraints.

**First Prototype:** Describes the initial implementation of the VR training tool, including its architecture, core features, and modes of use. It includes a discussion of the testing methodology and results from the preliminary evaluation.

**Second Prototype:** Presents the improvements made after user feedback and evaluation of the first prototype. It expands on enhanced functionality, usability changes, and additional features introduced to meet the updated requirements. It includes a more complex user testing phase and covers the submission of an academic paper on the work done.

**Conclusions:** Summarizes the main findings, contributions, and limitations of the research. It also outlines directions for future work and reflects on the broader implications of the platform in the context of immersive training and authoring.

# Chapter 2

# Literature Review

This chapter outlines the literature review process and what was learned from it. Conducting a proper review is paramount to successful research, and with this in mind, some tried and true methods and approaches were followed in order to provide good, consistent results that could be replicated by others should they follow the same process.

In this literature review, a two-step non-systematic format was considered. The first step was an Exploratory Review with the goal of identifying and defining key terms in the literature related to the topic of this thesis. In this step, a preliminary look into existing problems and future work to be done was also included.

The second step, a review of reviews, focuses on finding the most relevant surveys and reviews detailing the state of the art in Virtual Reality Training applications for the Industrial sector. The goal was to collect information about what had been done and to find gaps in the literature.

## 2.1 Exploratory Review

This preliminary review aimed to find popular terms in the topic of Virtual Reality Training Platforms, their definitions, and possible identifications of future work.

To do this, the source Google Scholar was used. This step was started by searching the expressions "Virtual Reality Training Platform", "Authoring tool", and "Virtual Choreographies" and ordering the results by relevance within Google Scholar. The first expression, "Virtual Reality Training Platform," provided results that seemed more promising than those of the other two expressions, so the first 5 articles were selected for a preliminary analysis, while only the first results of the other two expressions were considered. This preliminary analysis involved reading the abstract, introduction chapters, and final conclusions, and taking notes on the terms used as well as what their definitions were.

This Exploratory Review was also helpful to better understand and define the title of this thesis.

### 2.1.1 Title Definition

The title chosen for this thesis, "VRTraining 3D Authoring Tool for Industrial Training using Virtual Choreographies", can be broken down into a few categories of interest. These are "VRTraining 3D", "Authoring Tool", and "Industrial Training using Virtual Choreographies". The first category, "VRTraining 3D" is the foundation of this work. A platform that allows the training of industrial workers through the use of Virtual Reality and virtual environments. Due to its potential, this approach to training can be very beneficial to both companies and their workers, and create a safer and better workforce.

The topic of an "Authoring tool" is also very important for this work since, without it, the cost for developing software for training would be very high due to the need to create domain specific software with little interoperability and also high maintenance costs to keep the training up to date. An authoring tool also allows trainers to more precisely tweak the training environment to suit the needs of their trainees and what the tasks they perform require.

Lastly, "Industrial Training using Virtual Choreographies" emphasizes the educational and practical aspects of this work, as a training platform holds no value if it cannot effectively prepare trainees for real-world industrial procedures. Using immersive environments enhanced with Virtual Choreographies, it becomes possible to train workers in rare, complex, or hazardous scenarios within a controlled, risk-free setting. This approach allows repetition and refinement, enabling trainees to repeat tasks as often as necessary until proficiency and confidence are achieved.

The title for this thesis successfully encompasses its main areas of interest and also includes key terms, which are useful should any other researcher attempt to find papers on any of the aforementioned topics in the future.

### 2.1.2 Definition of terms

#### 2.1.2.1 Training

Training is a process that involves acquiring knowledge, improving an existing skill, obtaining a new one or even enhancing the abilities of an individual (trainee) (Xie et al. 2021). Training methods can vary depending on the context, but usually mean studying a topic to improve domain-specific knowledge or repeating actions until they become second nature. This process is often supervised by trainers who not only speed it up but also ensure that high-quality training occurs. Trainers are individuals who possess expertise in the area being trained and guide and help trainees achieve proficiency in the trained skills.

#### 2.1.2.2 Virtual Reality

The use of computer hardware and software to provide interactive and visualization capabilities in a virtual environment, thus providing an immersive and interactive experience (Zhang et al. 2022). In Virtual Reality, technology is used in a way that stimulates one or more senses to convey a new sense of reality to the user (Xie et al. 2021). The most common option at the time of writing is the

use of Head Mounted Displays (HMD) and game-like controllers to allow for this interaction and immersion. Combining HMD with advanced sound effects can also improve the experience.

#### 2.1.2.3 VR Training Platform

A VR Training Platform is any tool that uses technology to create an immersive and interactive training experience through the use of virtually generated environments (Xu and Zheng 2021). These environments replicate real-world scenarios with the goal of allowing trainees to practice and be evaluated on their skills and knowledge on conducting specific tasks, in the hopes that this training can then be transferred to the real world (Xie et al. 2021). These types of platforms allow companies to train employees in a safe, controlled, and cost-effective environment (Abich et al. 2021), where even the most dangerous and unlikely scenarios can be explored.

#### 2.1.2.4 Virtual Choreographies

Set of actions linked to an environment that facilitates the understanding of said actions by using a higher semantic level (Fernando Cassola et al. 2022). This is done by matching action data with the context and purpose in which they are applied instead of handling pure raw data (Fernando Cassola et al. 2021). Virtual Choreographies allow recorded actions to be translated into a more human-readable format, which facilitates their study and analysis.

#### 2.1.2.5 VR Authoring tool

Tool that allows users of a Virtual Reality platform to design and create virtual environments intuitively and without the need for professional developer skills (Fernando Cassola et al. 2021). Such tools allow software to be more generalized whilst giving the end users the ability to take advantage of it in a domain specific way. This means software will be more easily kept up to date, since users can adapt it as its objectives change over time and also, that it can appeal to a much broader audience.

### 2.1.3 Limitations

During this preliminary search, a few limitations were found in the literature. A key aspect is the low number of reviews available, or more accurately, the low amount of reviews that can be compared to give a sense of the state of the art. Due to the lack of a standard method to evaluate VR training platforms, the studies that exist are often not able to complement each other, and some bias cannot be excluded due to the type of experiments conducted or the population selected for testing (Abich et al. 2021). Many reviews and articles also focus on proving a concept and fail to prove if it is a better alternative than conventional methods, and do not provide proper efficiency evaluation.

### 2.1.4 Future Work

Regarding future work, some of the aspects identified include improving interaction techniques that complicate the user experience, allowing interoperability with other platforms, and creating standardized methods for performance assessment. Here are some notions of the future work identified:

- Find alternatives for the usage of a virtual keyboard with controllers (Fernando Cassola et al. 2022);
- Interoperability with web-based learning management systems (Fernando Cassola et al. 2022);
- More flexibility for matching actions to choreography elements (Fernando Cassola et al. 2022);
- Creating a standard method to evaluate training effectiveness using VR (Abich et al. 2021);
- Assess the benefits and drawbacks of using AR for training instead of VR (Abich et al. 2021).

## 2.2 Literature Review

### 2.2.1 Source Selection

Sources were chosen based on the contributions they provided for this literature review. This involved using sources capable of providing reliable, peer-reviewed papers with a high number of citations as well as being up-to-date. In the end, the following sources were used:

- **Scopus:** Known for using reliable sources with high quality peer-reviewed papers, indexed from reputable journals and conference proceedings. It is also one of the largest abstract and citation databases of peer-reviewed work and allows advanced search via search strings.
- **IEEE Digital Library:** This digital library focuses on cutting-edge, high-quality research on Engineering and Technology and provides access to IEEE standards, which are widely used in research practices. Alongside these advantages, it is also a trusted source for engineering professionals and is frequently updated, ensuring up-to-date work is always available.

### 2.2.2 Building the Search String

Building the search string was an iterative process with multiple steps in an attempt to provide the best results for analysis.

#### 2.2.2.1 Identification of Terms and Synonyms

To begin constructing the search string, a list of terms and synonyms was first required. The topic for this review was characterized by four key terms extracted from previous phases: VR Training

Platforms, Industrial Training, VR Authoring Tool, and *Virtual Choreographies*. By expanding on these terms, the synonyms present in Table 2.1 were found.

| **VR Training Platforms** | **Industrial Training** | **VR Authoring Tool** | **Virtual Choreographies** |
|---|---|---|---|
| AR Education Platform | Education Experts | Authoring Tool | Behavior Patterns |
| AR Training Platform | Expert Trainers | Content Creation | Orchestration |
| Acquiring Knowledge | Industrial Learning | Virtual Reality Authoring Tool | Process Models |
| Augmented Reality Education Platform | Industrial Simulation | | Scripts |
| Augmented Reality Training Program | Industrial Training | | Sets of Actions |
| Developing Skills | Effectiveness | | Spectrum of Tactics |
| Experiential Learning | Industrial Education | | Task Sequences |
| Extended Reality Education Platform | Industrial Formation | | Virtual Choreography |
| Immersive Environment | Industrial Practice | | Workflow Models |
| Interactive Environment | Industry Training | | |
| Simulation | Qualified Training Instructors | | |
| Simulation Training | Teaching Workers | | |
| Training Simulator | Training Objectives | | |
| VR Education Platform | Training Effectiveness | | |
| Virtual Environment | Training Instructors | | |
| Virtual Environments | Workforce Training | | |
| Virtual Reality Education Platform | | | |
| Virtual Reality Training Platform | | | |
| Virtual Space | | | |
| Virtual Spaces | | | |
| XR Education Platform | | | |
| XR Training Platform | | | |

Table 2.1: List of terms and their synonyms.

#### 2.2.2.2 Assembly of Search String

To assemble the search string, the terms and synonyms were taken into account, but some exclusion and inclusion checks were also added. The inclusion checks made sure to include only **Surveys** or **Reviews**, and the exclusion checks excluded all papers that were not in **English** or **Portuguese**. This procedure led to the following search string:

- ( TITLE ( "survey" OR "review" ) AND TITLE-ABS-KEY (("Industrial training" OR "Education experts" OR "Expert Trainers" OR "Industrial Learning" OR "Industrial Simulation" OR "Industrial Training effectiveness" OR "Industrial education" OR "Industrial formation" OR "Industrial practice" OR "Industry Training" OR "Qualified training instructors" OR "Teaching workers" OR "Training Objectives" OR "Training effectiveness" OR "Training instructors" OR "Workforce Training") AND ("VR Authoring tool" OR "Authoring tool" OR "Content creation" OR "Virtual Reality Authoring tool" OR "VR Training Platforms" OR "AR Education Platform" OR "AR Training Program" OR "Acquiring Knowledge" OR "Augmented Reality Education Platform" OR "Augmented Reality Training Program" OR "Developing skills" OR "Experiential Learning" OR "Extended Reality Education Platform" OR "Extended Reality Training Platform" OR "Immersive Environment" OR "Interactive Environment" OR "Simulation" OR "Simulation Training" OR "Training Simulator" OR "VR Education Platform" OR "Virtual Environment" OR "Virtual Environments" OR "Virtual Reality Education Platform" OR "Virtual Reality Training Platform" OR "Virtual Space" OR "Virtual Spaces" OR "XR Education Platform" OR "XR Training Platform" OR "Virtual Choreographies" OR "Behavior patterns" OR "Orchestration" OR "Process models" OR "Scripts" OR "Sets of actions" OR "Spectrum of tactics" OR "Task sequences" OR "Virtual choreography" OR "Workflow models"))) AND ( EXCLUDE ( DOCTYPE , "ch" ) OR EXCLUDE ( DOCTYPE , "er" ) OR EXCLUDE ( DOCTYPE , "no" ) OR EXCLUDE ( DOCTYPE , "dp" ) ) AND ( EXCLUDE ( LANGUAGE , "Chinese" ) OR EXCLUDE ( LANGUAGE , "German" ) OR EXCLUDE ( LANGUAGE , "Italian" ) OR EXCLUDE ( LANGUAGE , "Russian" ) OR EXCLUDE ( LANGUAGE , "Japanese" ) OR EXCLUDE ( LANGUAGE , "Korean" ) OR EXCLUDE ( LANGUAGE , "Turkish" ) OR EXCLUDE ( LANGUAGE , "Hungarian" ) OR EXCLUDE ( LANGUAGE , "Undefined" ) OR EXCLUDE ( LANGUAGE , "Bosnian" ) OR EXCLUDE ( LANGUAGE , "Malay" ) OR EXCLUDE ( LANGUAGE , "Persian" ) )

This search string consists of an AND between the term "VR Training Platforms" and the respective synonyms separated by ORs, and the remaining terms and respective synonyms separated as well by ORs. This disposition was chosen to focus on finding papers about Virtual Reality that mention some of the other terms. Multiple dispositions were experimented with, but they either provided results that were too specific or completely unrelated.

### 2.2.3 Inclusion and Exclusion Criteria

In order to test the eligibility of the reviews or surveys retrieved, some inclusion and exclusion criteria were defined. The defined criteria aim to filter out articles that are not surveys or reviews and only include those that are. They also filter papers that are outdated (older than 1990) or not in Portuguese or English. At last, the criteria selects only those reviews that are relevant to the research questions defined previously. The criteria chosen are present in Table 2.2

| **Type** | **Criteria** |
|---|---|
| **Inclusion** | Is a Review or a Survey |
| | Relevant to at least 1 RQ |
| **Exclusion** | Language not in English or Portuguese |
| | Not a Review or Survey |
| | Not relevant to any RQ |
| | Published before 1990 |

Table 2.2: Inclusion and Exclusion Criteria.

### 2.2.4 Screening Process and Results

Upon inputting the search string in the mentioned databases, a total of **1198 results** were retrieved, **72** from **Scopus** and **1,126** from **IEEE Digital Library**. Note that for IEEE, a simplified version of the search string with only AND and OR commands was needed and used. For the results of the IEEE Digital Library, only the 50 most relevant were considered since it was not possible to filter by reviews or surveys.

After duplicate removal, **68 articles from Scopus and 50 from IEEE Digital Library** were left to apply the search criteria.

By applying the inclusion and exclusion criteria to the previous results, all 50 papers retrieved by IEEE were removed. Regarding the articles retrieved from Scopus, a combination of applying the search criteria and reading the titles and abstracts reduced the number to **18 reviews**.

Lastly, by going deeper into the analysis of these 18 reviews retrieved by Scopus, 12 articles were excluded, leaving **6 reviews** for full-text analysis.

These results can be found in Table 2.3 and the process in Figure 2.1.

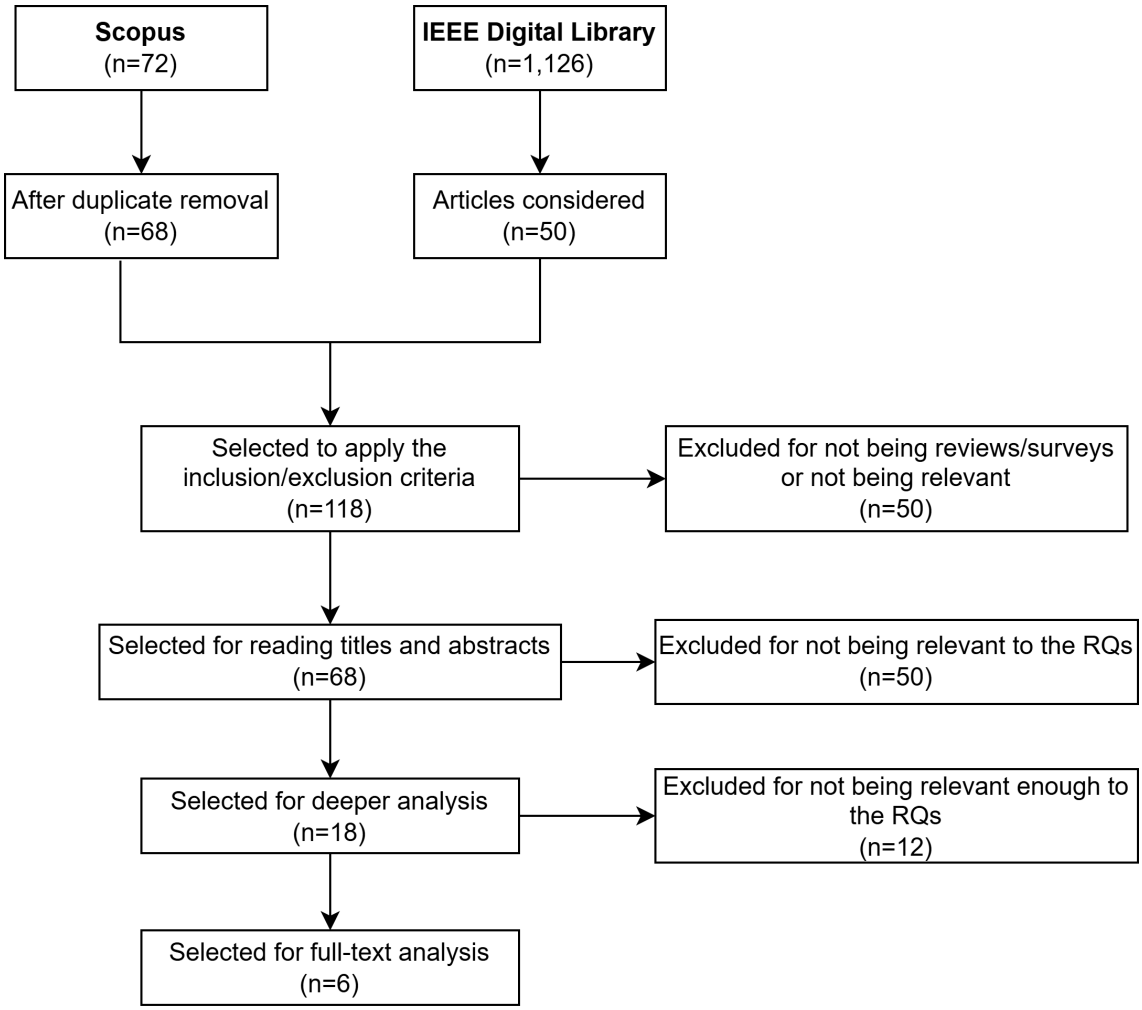



Figure 2.1: Diagram of the article selection process.

| Code | Review Title |
|---|---|
| P01 | A review of the evidence for training effectiveness with virtual reality technology (Abich et al. 2021) |
| P02 | Operator training simulators in virtual reality environment for process operators: a review (Patle et al. 2019) |
| P03 | Effectiveness of VR Head Mounted Displays in Professional Training: A Systematic Review (Renganayagalu, Mallam, and Nazir 2021) |
| P04 | A Review on Enabling Technologies of Industrial Virtual Training Systems (Singhaphandu and Pannakkong 2024) |
| P05 | A Survey on Future of Augmented Reality with AI in Education (Kaviyaraj and Uma 2021) |
| P06 | A Review on Virtual Reality Skill Training Applications (Xie et al. 2021) |

Table 2.3: Reviews for Semantic Analysis.

## 2.3 Conclusions

The literature selected and analyzed provided important insights on the state of Virtual Reality Training Applications for Industrial settings, showcasing what has been done in recent years in the research of this topic. By applying the focus on Virtual Reality Training, the literature revealed a broader range of its application in educational formats, setting a foundation for future work. The results displayed a lack of reviews regarding topics like Virtual Choreographies, VR Authoring tools, and Assessment of Training Efficiency and Efficacy for Virtual Reality Training. This indicates a gap in the literature with great potential for research.

Addressing these gaps could not only provide a more comprehensive understanding of the topic but also enhance the practical applications of VR as a training tool. Based on this, future research should attempt to dive deeper into the applications of Virtual Choregraphies for training scenarios and how Authoring tools could be used to provide a more customizable experience. Another important topic that lacks research is the performance assessment of training using Virtual Reality, especially in Industrial environments.

# Chapter 3

# State Of The Art

This chapter provides a comprehensive review of the current state of the art in Virtual Reality Training platforms. It addresses several stages, such as their development, possible applications, and known limitations. It explores key advancements in the field, with particular emphasis on the characteristics and features that a VR training tool needs, the limitations current systems face, as well as the assessment of training efficacy.

By looking into these topics, this chapter identifies existing gaps and trends, establishing a foundation for the contributions of this thesis.

## 3.1 Methodology

This section describes the process used to understand the state of the art and the techniques used to extend the previous chapter of the literature review and analyze the surveys and reviews previously identified.

The diagram 3.1 describes this methodology.

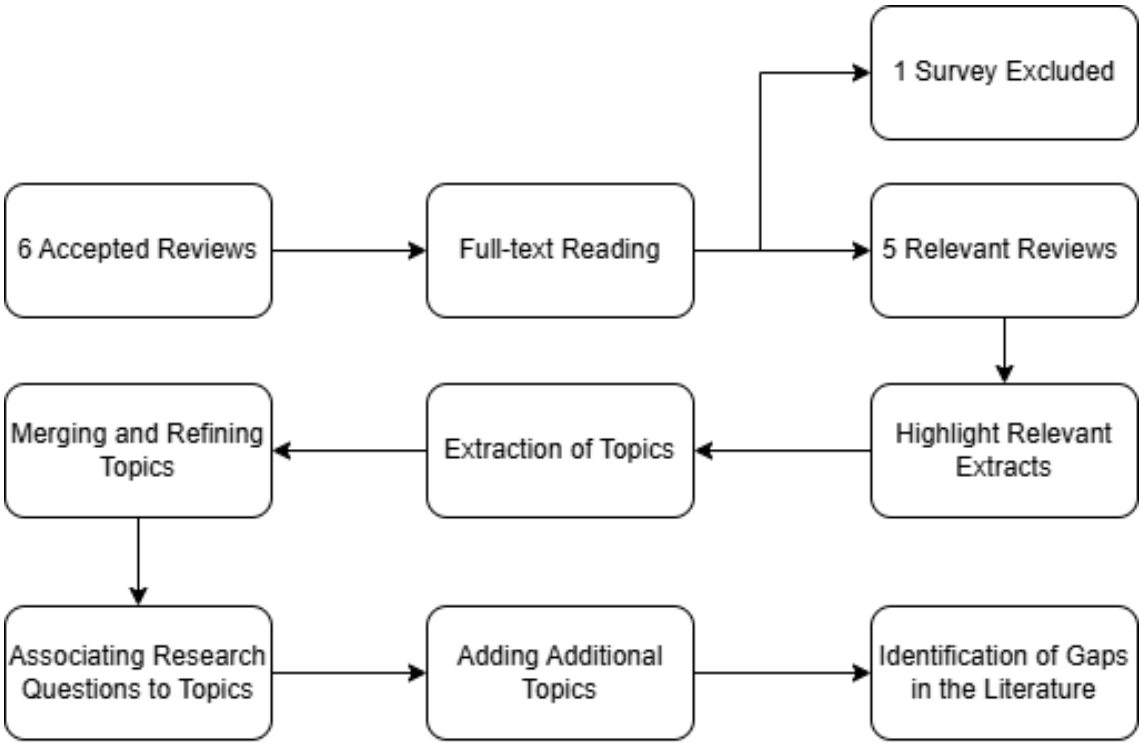



Figure 3.1: Diagram of the methodology used.

### 3.1.1 Full-text Reading and Relevant Extracts

In order to understand the State of the Art, the articles selected in the previous chapter were read in full text and analyzed. The purpose of this reading process was to understand the selected reviews and assess whether they are relevant to the research questions, as the previous phase of reading titles and abstracts can sometimes lead to the wrong papers being accepted.

Another important aspect of this step was the highlighting of important text extracts that were deemed relevant to the research questions and topics covered in this thesis, and the identification of future work directly identified in the reviews.

### 3.1.2 Classification of Extracts

The second step was the classification of the extracts by associating them with the topics that they cover. This was done by going through each piece of text and identifying what that text was about in a higher level of abstraction, and as simply as possible. The topics were then written down if they had not been previously created.

Each identified topic was given a numeric code to facilitate the association where the same topic is present in more than one extract or when one piece of text contains more than one topic.

### 3.1.3 Topic Refinement and Merging

The previous step is prone to generating topics that are redundant or too specific, especially when dealing with a large number of text extracts. This creates a need to further refine this selection and merge topics that describe similar aspects.

The topics need to be compared to each other to find possible associations and broader terms to define the area of study in which they occur. During this step, it is important to keep the research questions in mind to avoid abstracting the topics too much from the goal, as this can hinder the proper identification of the themes.

The end goal is to have meaningful themes about the work that is being done that do not overstep on each other and that are not too abstract.

### 3.1.4 Research Questions and Topic Association

Switching the focus onto the research questions, there should be a clear link between each question and the topics that are relevant to said question. The same topic can be associated with more than one research question, but they should relate in a way that understanding the topic more deeply helps answering the research question.

This step is crucial to pinpoint which areas need to be researched in order to find useful information that satisfies the research questions.

### 3.1.5 Redefined List of Terms

The entire process described should result in an association of research questions and the topics they regard. However, in some cases, the literature choice is flawed or has gaps in the information, and thus, the topics identified might not be enough to cover all the aspects of the research questions.

To address that issue, the final step of this research process requires the researcher to add topics that are also deemed relevant but were not identified. These added topics can be part of previous phases, such as the literature review, or conjured based on previous knowledge in the area. The key notion here is that despite the fact that these topics were not identified in the literature, their addition can only improve the quality of the research as it creates a more thorough approach.

## 3.2 Results

This section describes the results obtained from each phase of the thematic analysis for this State of the Art chapter, following the methodology described previously

### 3.2.1 Relevant Extracts Identified in Text

The Figure 3.2 displays the number of extracts deemed relevant for this work. Although it is not the most accurate measure of the value of a paper, it hints towards the usefulness of an article for the research questions considered.

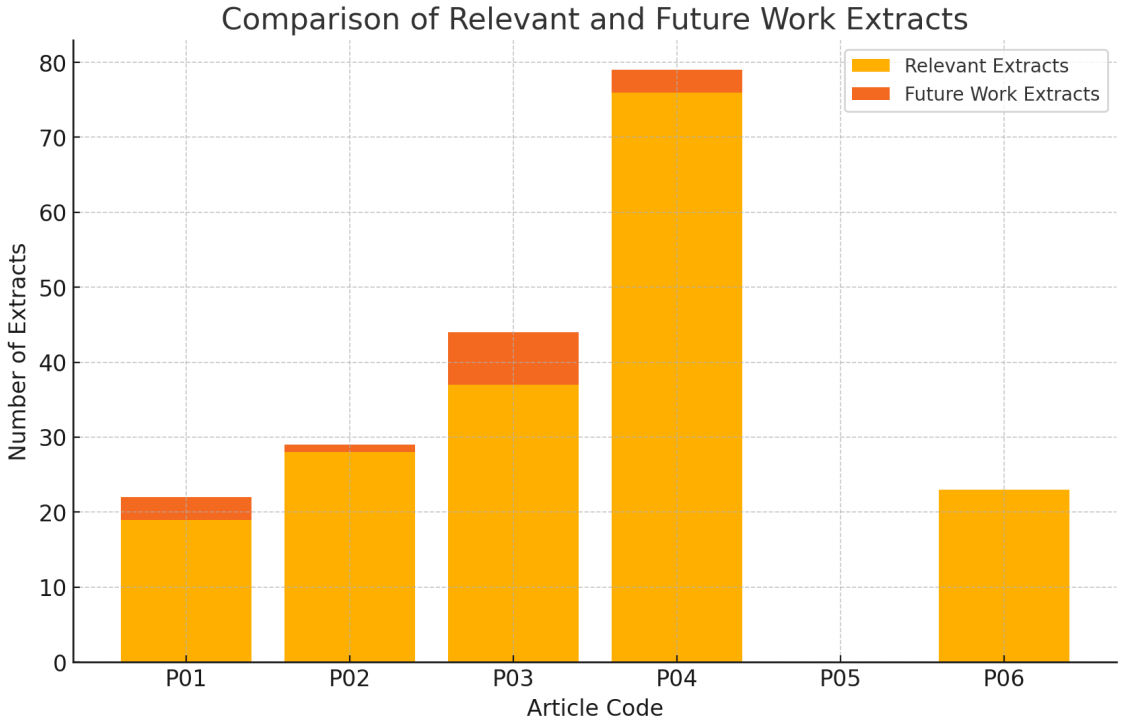



Figure 3.2: Summary of Relevant Extracts and Future Work Extracts.

The figure also shows that no relevant text was identified in the review with code P05. Despite being selected in the literature review, this survey was not deemed relevant for this work and was therefore not considered in the next steps.

It also indicates that the amount of future work directly identified was considerably lower in comparison to the total extracts retrieved. This, however, is a measure that needs to be analyzed with caution because it might lead one to think that there is little to no future work to be done, which is not true. In this case, the low number of mentions of future work is due to them being situated in the same section of the reviews and therefore being retrieved as a single extract. It also comes from the fact that the reviews that were considered also included a few implicit mentions of future work, which was not extracted for this phase.

Lastly, the total number of relevant extracts was considered enough to provide a proper analysis of the topics covered by the reviews.

### 3.2.2 Classification of Extracts

The analysis of the extracted text led to the identification of **33 distinct topics** which appeared with varying frequency, as illustrated in Figure 3.3. The graph highlights the frequency of each topic across the literature, offering key insights into their relative significance.

The high frequency of topics such as "Benefits of VR Training", "Characteristics of VR Training", and "Improving VR Training" highlights their importance in the field of VR Training, which is the foundation of this work. Their prominence suggests that these areas have been well explored, reflecting their fundamental role in advancing knowledge and practice in VR Training. Having extensive information on these topics is beneficial for this work, as it enables a robust grounding in the established literature.

On the other hand, the low frequency of certain topics, such as "Characteristics of Virtual Environments" and "Importance of Instructors", may point to potential gaps in the literature. These underrepresented topics might indicate areas that warrant further investigation or areas that have been overlooked. Exploring these lesser-studied topics could provide valuable contributions by addressing existing gaps and enriching the overall understanding of the field.

This duality of value allows for a balanced approach that considers the strengths of the more explored areas while acknowledging the potential for further exploration in lesser-explored areas.

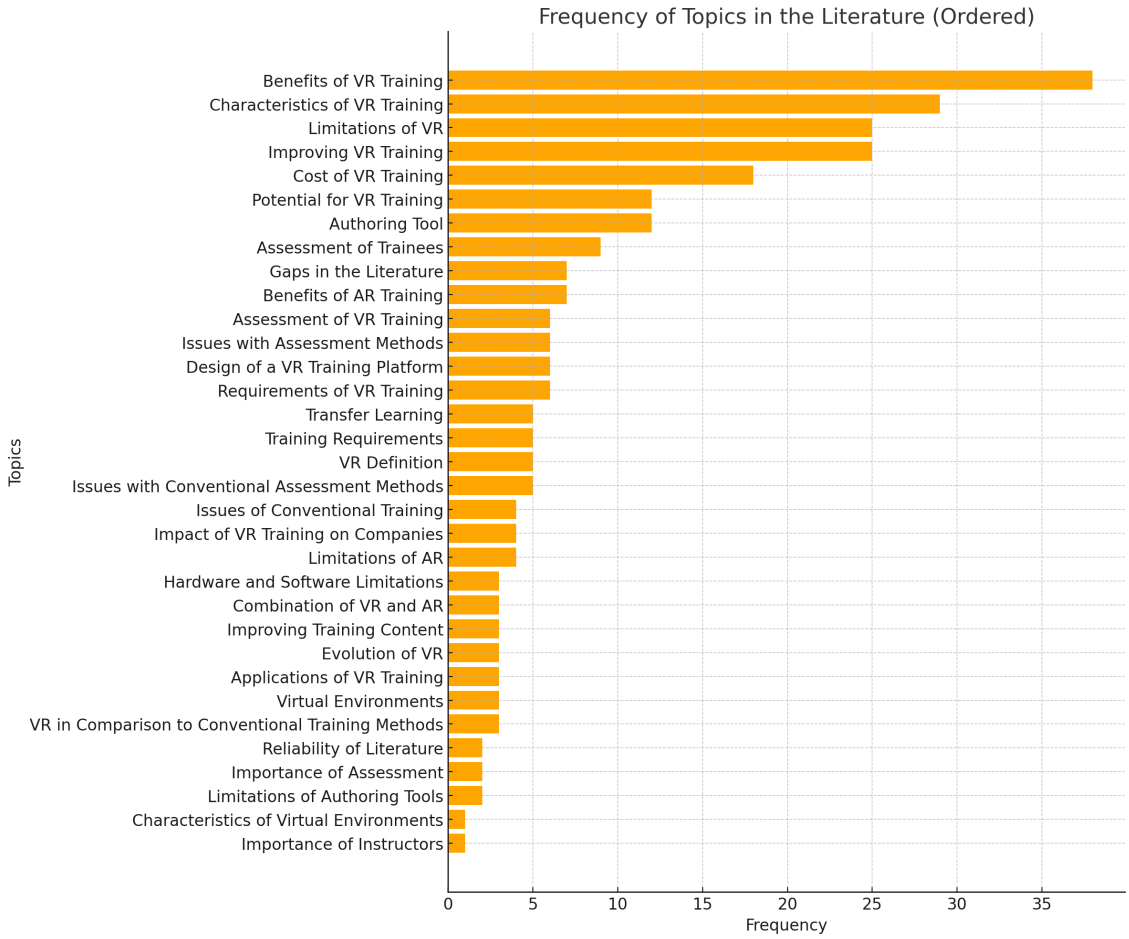



Figure 3.3: Frequency of Topics in the Literature.

### 3.2.3 Topic Refinement and Merging

The creation of the grouped Table 3.4 represents an intentional effort to organize the identified topics into broader, thematically connected categories without losing the level of detail required for this work. This approach simplifies the complexity of the dataset by consolidating related topics under unified groupings, such as **"Benefits of VR Training"**, **"Limitations of VR Training"**, and **"Issues of Assessment"**. By doing so, the table provides a clearer, high-level understanding of the key thematic areas that emerge from the literature.

This grouping process serves to identify core themes within the research, enabling a more focused analysis of the literature. For instance, merging topics like "Potential for VR Training" with "Benefits of VR Training" illustrates how overlapping concepts can be streamlined for clarity without losing their distinct contributions. At the same time, the categorization respects the nuanced differences between related topics, such as "Issues with Assessment Methods" and "Issues with Conventional Assessment Methods", ensuring the integrity of the insights.

Moreover, the grouped table reveals patterns in the literature, highlighting areas of strong representation and those with limited coverage. Topics with fewer occurrences, such as "Limitations

of Authoring tools", suggest potential gaps in the literature that warrant further investigation. By identifying these gaps, the table provides a basis for future research to address under-explored areas and expand the existing knowledge base.

| Benefits of VR Training | Limitations of VR Training | Characteristics of VR Training | VR Authoring | Issues of Assessment |
|---|---|---|---|---|
| Benefits of VR | Limitations of VR | Characteristics of VR Training | Authoring Tool | Issues with Assessment Methods |
| Potential for VR Training | Limitations of AR | Applications of VR Training | Design of a VR Training Platform | Issues with Conventional Assessment Methods |
| Benefits of AR Training | Hardware and Software Limitations | Characteristics of Virtual Environments | Virtual Environments | |
| | Limitations of Authoring Tools | | Improving Training Content | |
| | | | Characteristics of Virtual Environments | |

Figure 3.4: Table of the Merged Topics.

### 3.2.4 Research Questions and Topic Association

The research questions identified in section 1.4 serve as the foundation of this research step and, in order to answer them, we need to situate them in the literature. This was done by creating associations between the topics previously identified and each question, as displayed in table 3.5 and described below:

- **RQ1a:** What characteristics are necessary in a VR training platform to provide an adequate and up-to-date training?
  - **Topics:** "Benefits of VR Training", "Characteristics of VR Training", "Limitations of VR Training", "Improving VR Training", etc.
  - These topics highlight essential features such as interactivity, scalability, adaptability, and immersion that ensure a VR training platform remains current and effective.
- **RQ1b:** What characteristics are necessary in a VR training platform to allow educators to certify trainees?
  - **Topics:** "Issues of Assessment", "Importance of Instructors", "Assessment of VR Training", etc.
  - These areas explore how platforms can integrate robust assessment tools and ensure that trainers can reliably evaluate and certify skills.
- **RQ2:** How can virtual choreographies be incorporated in a VR training platform to help trainers understand user actions and create new courses?
  - **Topics:** "Characteristics of Virtual Environments", "Authoring tool", "Virtual Environments", etc.
  - Virtual Choreographies enable trainers to record, understand, and analyze user interactions in meaningful ways, thereby supporting course creation and adaptation.

- **RQ3:** How can a virtual training platform work with professional trainers instead of attempting to replace them?
  - **Topics:** "Importance of Instructors", "Improving Training Content", "Training Requirements", etc.
  - These topics focus on the collaborative nature of VR Training platforms, emphasizing tools and features that complement trainers rather than replace them.

By looking deeper into the table, we can see that many of the topics are relevant for RQ1a, indicating an abundance of information regarding that question, which might allow the formulation of a complete and thorough answer. Research questions RQ1b and RQ3 also had a decent number of relevant topics identified. However, RQ2 did not fair the same outcome. This suggests that the literature is lacking in terms of *Virtual Choreographies* applied to training with Virtual Reality.

| RQ1a | RQ1b | RQ2 | RQ3 |
|---|---|---|---|
| Benefits of VR Training | Issues of Assessment | Characteristics of Virtual Environments | Importance of Instructors |
| Limitations of VR Training | Assessment of Trainees | Limitations of Authoring tools | Importance of Assessment |
| Characteristics of VR Training | Assessment of VR Training | Virtual Environments | Impact of VR Training on Companies |
| VR Authoring | Training Requirements | Authoring tool | Assessment of Trainees |
| Design of a VR Training Platform | Transfer Learning | | Assessment of VR Training |
| Improving VR Training | Importance of Instructors | | Training Requirements |
| Cost of VR Training | Importance of Assessment | | Improving Training Content |
| Requirements of VR Training | | | |
| Requirements of Training | | | |
| Improving Training Content | | | |

Figure 3.5: Associations between Topics and Research Questions.

### 3.2.5 Redefined List of Terms

Throughout the literature review and thematic analysis, several terms were refined or expanded to better reflect their significance and usage in this research. These terms helped to specify the areas of knowledge that should be explored in order to answer the research questions for this thesis.

Despite following a strict scientific method and thoroughly analyzing the selected reviews, the resulting terms were not enough. Gaps in the literature or a sample too small from it can cause some topics to not be covered, as was the case in the table from the previous step. By simply looking at Table 3.5, it is clear that some important aspects of the research questions were not mentioned. To fix this, some terms were added. These were derived from previous knowledge in the area and were intended to broaden the search for relevant information for the research questions and to increase the level of detail of this work.

The work of the previous steps also indicated a high complexity for the second research question, RQ1b, whose scope exceeded that of this thesis. In an attempt to maintain a high-quality research process whilst avoiding veering off topic, it was decided to no longer consider that question and remove it from the research questions. This meant that for the next phases of this thesis, RQ1a (now RQ1), RQ2, and RQ3 are the questions to be answered.

The table 3.6 presents the finalized list of terms associated with each research question. Removed terms are highlighted in red, while newly added terms are marked in yellow. This visualization effectively illustrates the extent of modifications made, emphasizing the number of terms that had to be introduced and identifying the areas where the reviews analyzed showed the greatest deficiencies.

| RQ1a | RQ1b | RQ2 | RQ3 |
|---|---|---|---|
| Benefits of VR Training | Issues of Assessment | Characteristics of Virtual Environments | Importance of Instructors |
| Limitations of VR Training | Assessment of Trainees | Limitations of Authoring tools | Importance of Assessment |
| Characteristics of VR Training | Assessment of VR Training | Virtual Environments | Impact of VR Training on Companies |
| VR Authoring | Training Requirements | Authoring tool | Assessment of Trainees |
| Design of a VR Training Platform | Transfer Learning | Virtual Choreographies | Assessment of VR Training |
| Improving VR Training | Importance of Instructors | Sets of actions | Training Requirements |
| Cost of VR Training | Importance of Assessment | Behavior patterns | Improving Training Content |
| Requirements of VR Training | Certification | Process models | Expert Trainers |
| Requirements of Training | | Workflow models | Qualified training instructors |
| Improving Training Content | | Task sequences | Training instructors |
| Content creation | | Spectrum of tactics | |
| | | Orchestration | |
| | | Scripts | |

Figure 3.6: Refined List of Terms with Merged and Added Topics.

## 3.3 Observations

### 3.3.1 Gaps in the literature

The existing literature on VR training platforms reveals several significant deficiencies. One of the most notable gaps is the lack of standardized methodologies for evaluating the effectiveness and efficiency of these platforms. Without these benchmarks, it becomes challenging to compare systems or validate their real-world applicability in a consistent manner.

Another key deficiency is the lack of detailed information regarding the role of instructors within virtual training platforms. The interaction and collaboration between instructors and trainees in VR environments remain poorly understood, leaving an important aspect of training effectiveness unexplored. Similarly, the use of *Virtual Choreographies* in VR training platforms has received minimal attention, despite their potential to enhance the understanding and analysis of user

actions.

Additionally, there is a significant gap in the integration of Virtual Choreographies with authoring tools specifically designed for VR. *Virtual Choreographies*, which provide a semantic approach to recording and interpreting user actions, could significantly enhance the functionality of authoring tools by enabling trainers to design adaptive and context-aware training modules. However, the lack of research into their combined use leaves questions about how these tools can be optimized to streamline customization, foster interactivity, and improve the adaptability of training scenarios for diverse industries and user groups.

Lastly, research on the various types of interactions possible within VR systems is notably sparse. Interactions in VR can range from physical gestures and voice commands to gaze-based navigation and controller inputs, each offering unique advantages and challenges. Without a comprehensive analysis of these interaction types, it remains unclear how to optimize their implementation to cater to diverse learning needs and scenarios effectively. This limits our understanding of how interaction styles affect user engagement, learning outcomes, and overall system usability.

### 3.3.2 Future Work Identified

Future research on VR training platforms should address several pressing areas to ensure their development and widespread applicability. First, efforts could focus on reducing costs associated with both the development and operation of VR training platforms. This includes exploring cost-effective technologies and scalable solutions to make VR more accessible to a broader audience.

Standardization remains a critical area, particularly for assessment methodologies. Developing uniform standards for evaluating the effectiveness of VR training tools will facilitate meaningful comparisons with conventional training methods. This should be coupled with proper assessments to rigorously analyze the relative advantages and limitations of VR training compared to traditional techniques.

Another key area for future research involves investigating the usability, ergonomics, quality of experience, and the effects of prolonged VR usage for training purposes. These factors play a vital role in determining the practicality and safety of VR environments for extended educational sessions.

Long-term studies are also essential to assess knowledge retention among trainees. By evaluating how well trainees retain and apply learned skills over time, researchers can establish the true efficacy of VR as a learning medium.

Additionally, integrating knowledge management strategies (KMS) into VR training platforms presents a promising avenue for enhancing information organization, retrieval, and application within immersive environments. Experimenting with such integrations could lead to more dynamic and effective training ecosystems.

## 3.4 Conclusions

This chapter has provided a comprehensive overview of the current state of the art in VR training platforms, identifying key advancements and limitations that shape the field. Through the thematic analysis, critical areas of focus have emerged, offering a foundation for addressing gaps in research and guiding future innovations.

A significant finding of this review is the strong emphasis on the benefits and characteristics of VR training, which highlight its potential for education and professional development. However, the analysis also uncovered notable deficiencies, such as the lack of standardized assessment methodologies, insufficient exploration of instructor roles, and limited integration of *Virtual Choreographies* with Authoring Tools. These gaps represent opportunities to advance the effectiveness, usability, and adaptability of VR platforms.

The findings also emphasize the need for a deeper understanding of interaction types within VR environments and their implications for user engagement and learning outcomes. Similarly, integrating knowledge management strategies into VR platforms could unlock dynamic and efficient training ecosystems, paving the way for broader adoption and scalability.

In conclusion, this chapter has laid the groundwork for addressing the challenges in VR training platforms by identifying critical gaps and proposing pathways for future research. By building on these insights, the subsequent chapters of this thesis aim to contribute meaningfully to the development of more robust and adaptable VR training solutions.

# Chapter 4

# Adopting a Design Science Research Methodology

The selection of a structured research methodology is essential to ensure the rigor and relevance of any scientific investigation. This chapter outlines the adoption of the Design Science Research Methodology (DSRM), proposed by Peffers et al. 2007, in combination with the Three-Cycle Model (Hevner 2007). This serves as the theoretical foundation for this thesis. Using DSR, the research addresses both practical and academic objectives, ensuring the development of a VR Training Platform that meets the needs of educators and trainees.

## 4.1 Theoretical Foundation

### 4.1.1 Three-Cycle Design Science Research (DSR)

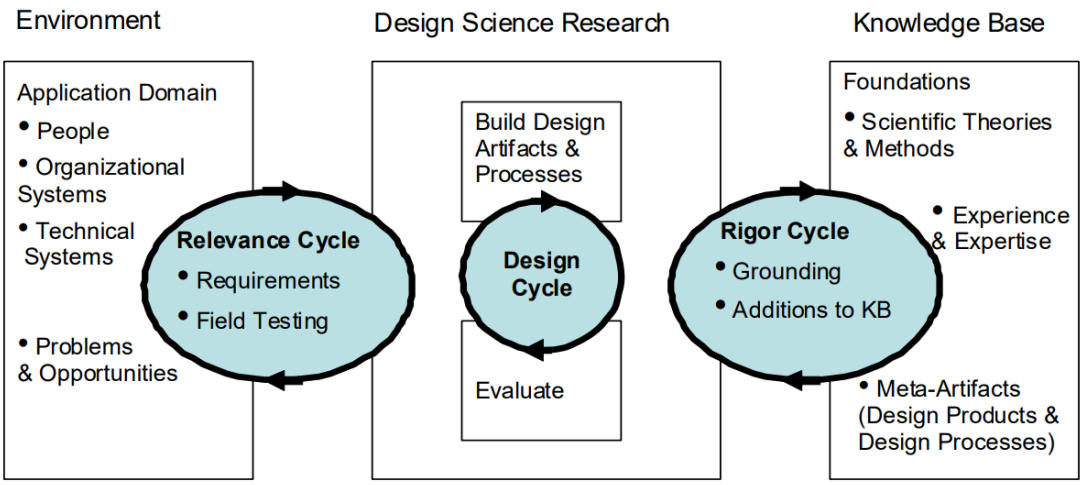



Figure 4.1: Design Science Research Cycles (Hevner 2007).

Design Science Research is a problem-solving paradigm that focuses on the creation and evaluation of artifacts to address identified problems. As seen in Figure 4.1 from Hevner 2007 it is structured around three key cycles:

- **Relevance Cycle:** Connects research with real-world application domains by identifying relevant problems and validating the solutions in practical environments.
- **Rigor Cycle:** Anchors the research on a solid theoretical foundation by leveraging existing knowledge bases and contributing new knowledge.
- **Design Cycle:** Involves iterative processes of artifact creation, refinement, and evaluation.

The adoption of DSR aligns well with the objectives of this thesis, as it ensures a balance between practical utility and theoretical contribution.

### 4.1.2 Research Methodology

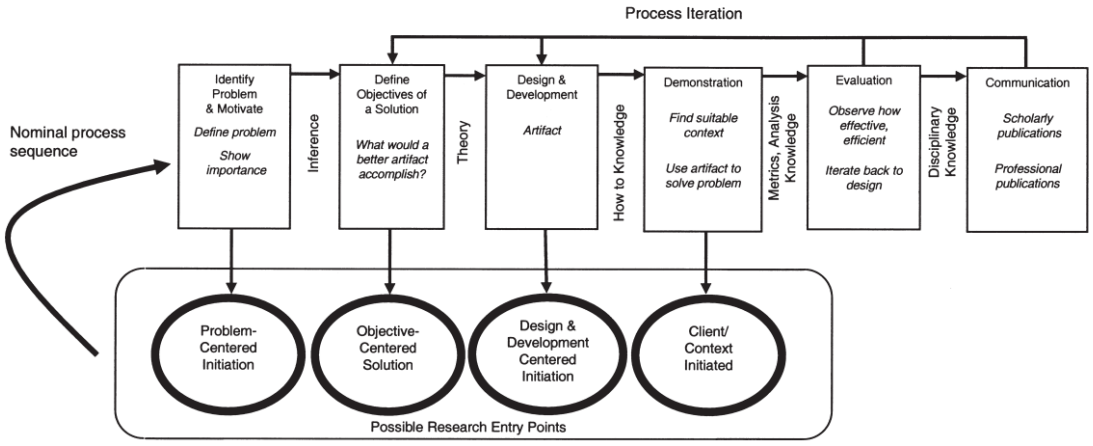



Figure 4.2: DSRM Process Model (Peffers et al. 2007).

The methodology used in this thesis follows the six steps of the Design Science Research Methodology (DSRM) proposed by Peffers et al. 2007 (Figure 4.2):

1. **Problem Identification and Motivation:** Definition of the problem and its importance.
2. **Objectives of a Solution:** Defining what an improved artifact should accomplish.
3. **Design and Development:** Creation of the artifact.
4. **Demonstration:** Using the artifact to solve a problem within a suitable context.
5. **Evaluation:** Assessing the effectiveness and efficiency of the artifact against predefined metrics. Results from this step are iterated back to the design step.
6. **Communication:** Presenting the research findings and the developed artifact to the respective audience.

## 4.2 Steps Adopted in This Thesis

### 4.2.1 Problem Identification and Motivation

This step involves defining the research problem and explaining its importance. It is a crucial step that guides the rest of the process and has been refined throughout the previous phases of this thesis (Chapter 1).

#### 4.2.1.1 Problem Identification

The problem revolves around the lack of an Industrial VR Training Platform that allows trainers without professional software development skills to create realistic and up-to-date training courses that can better prepare trainees in all kinds of procedures, while ensuring that these experts can be incorporated into the training to more closely guide their students.

This platform also needs to be adaptable to a changing environment, easy to use, and keep costs down. Interoperability with different types of devices is also required.

#### 4.2.1.2 Motivation

As mentioned in Section 1.2, there is great potential in a tool that allows industrial workers to train more efficiently to improve the quality of work, the safety of everyone involved, and reduce current training costs.

### 4.2.2 Objectives of a Solution

The solution to the problem mentioned in Section 4.2.1.1 can be broken down by the characteristics desired on an Industrial VR Training Platform. These characteristics refer to both technical and usability aspects that come together to create an effective learning experience that is transferred to real-world tasks.

These features are to be extracted from the State Of The Art (Chapter 3), such as known limitations and previously identified future work. Gaps in the literature can also contain important information that indicates new paths that have yet to be explored and that can bring positive outcomes.

### 4.2.3 Design and Development

During this step, the artifact is designed and developed. This is an iterative process that begins by designing a platform that incorporates the characteristics identified in previous stages and aligns them with the output of the evaluation process, depending on whether it is the first artifact or the result of a posterior iteration. The result should be a platform for Industrial VR Training that efficiently and elegantly solves the problem at hand.

In this thesis, two iterations are considered and detailed, resulting in a first and second prototype. Chapter 6 covers the beginning of the design and development process of the first prototype,

and Chapter 7 goes into detail on the second prototype, mentioning improvements over the previous version, as well as what was learned from the iteration. These iterations are crucial for gathering feedback and discovering points of improvement.

### 4.2.4 Demonstration

The demonstration step validates the artifact by applying it to practical use cases. In this thesis, the developed Industrial VR Training Platform will be tested in scenarios that closely mimic real-world industrial training environments. Trainers and trainees will interact with the platform, using it to create and execute customized training courses based on specific needs. This can be visualized in detail in Section 6.5 and Section 7.4, where published YouTube videos go through all the features of the developed artifacts.

The goal is to show that the platform can effectively address the identified problems, such as allowing trainers without technical expertise to design realistic training experiences and ensuring trainees can acquire and demonstrate relevant skills. The demonstration will involve the following:

- Simulated industrial environments to showcase the adaptability of the platform.
- User studies with trainers and trainees to test usability and functionality.
- Collecting feedback from stakeholders to refine the design iteratively.

These practical tests will help confirm the applicability of the artifact and provide insights into areas for improvement.

### 4.2.5 Evaluation

The evaluation step measures the effectiveness and efficiency of the artifact on the basis of predefined criteria. In this thesis, both prototypes were evaluated (Section 6.6 and Section 7.5) to assess their quality and discover improvement areas. The success of the artifact is to be evaluated against the following metrics:

- **Completeness:** Assess how many of the requirements are completed in full or partially.
- **Usability:** How intuitive and user-friendly the platform is for trainers and trainees.
- **Adaptability:** The ability of the platform to accommodate diverse training scenarios and changing requirements.
- **Educational Outcomes:** The extent to which trainees acquire and retain the skills and knowledge required for their roles.
- **Cost-Effectiveness:** Reduction in training costs compared to traditional methods or other VR platforms.

The evaluation process includes both qualitative and quantitative methods:

- **User Surveys:** Collect feedback on the platform's usability, adaptability, and overall effectiveness.
- **Performance Metrics:** Track trainee performance improvements, knowledge retention, and task completion rates.
- **Comparative Analysis:** Benchmark the artifact against existing training methods and tools to highlight its advantages and limitations.

The results guide further iterations of the design and development cycle, ensuring continuous improvement of the artifact.

### 4.2.6 Communication

The final step involves presenting the research findings and the artifact developed to both academic and professional audiences. This ensures the dissemination of knowledge and insights gained throughout the research process.

The communication strategy includes the following:

- **Academic Publications:** Submitting a paper to a peer-reviewed conference on virtual reality and the metaverse, educational technology, and industrial training. This has been highlighted in Section 7.9.
- **Thesis Documentation:** Provide comprehensive documentation in this thesis, detailing the methodology, design, and results for future reference.

By effectively communicating outcomes, the research aims to contribute to the broader scientific and industrial communities, inspiring further innovation in Industrial VR Training.

## 4.3 Integration with Existing Frameworks

The approach adopted in this thesis combines Peffers et al. 2007's DSRM with Hevner 2007's Three-Cycle Model. This integration ensures:

- Practical relevance by addressing real-world challenges in Industrial VR Training.
- Theoretical rigor by grounding the research in existing frameworks and advancing knowledge in the domain.
- A systematic process for artifact creation, refinement, and evaluation.

The methodology bridges the gap between theoretical research and practical implementation, ensuring that the outcomes are both scientifically robust and practically valuable.

## 4.4 Timeline

The research and development process for this thesis follows a structured timeline to ensure systematic completion of all tasks. Figure 4.3 presents a Gantt chart that outlines the key phases and milestones, including artifact development, testing, evaluation, and final thesis writing.

It allows for an easy visualization of the predicted timeline of the future steps in the development and refinement of the artifacts, as well as the completion of this thesis and the writing of a scientific paper about the topic.

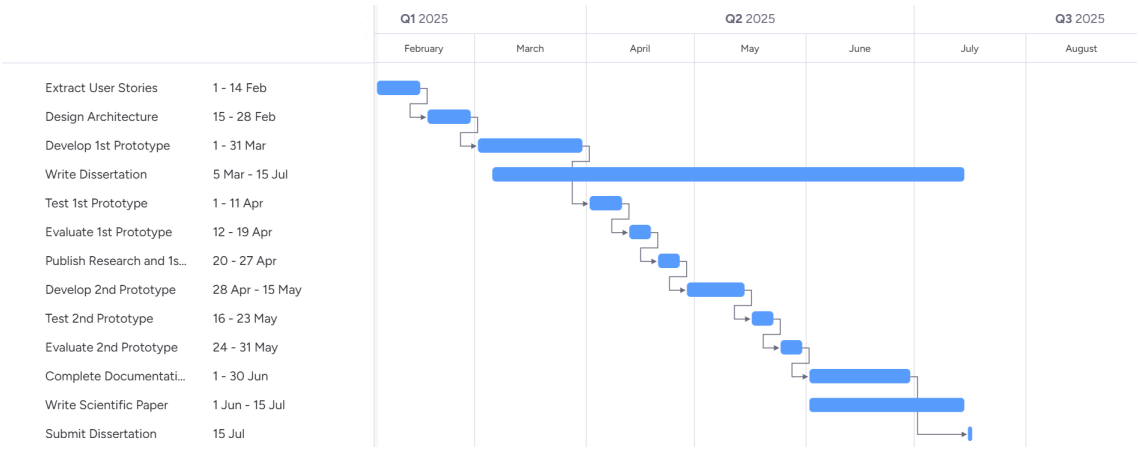



Figure 4.3: Gantt chart for this thesis.

## 4.5 Conclusions

This chapter has detailed the theoretical foundation and research methodology selected for this thesis. The adoption of the multiple stages of the Design Science Research Methodology (Peffers et al. 2007) along with the Three-Cycle Model (Hevner 2007) ensures that research maintains a balance between rigor and relevance.

The Relevance Cycle, as well as the first stage of the DSRM, Identification of the Problem and Motivation, is outlined in the Introduction Chapter [1]. The second stage, the Definition of the Objectives of a Solution, is addressed in the State Of The Art [3], and in the Requirements Chapter [5].

The Design Cycle aligns with the following 3 stages of the DSRM, the Design and Development, Demonstration, and Evaluation. To provide the best contribution possible within the available time frame, 2 iterations of this cycle were used. These were discussed in detail in the first and second prototype chapters (Chapter 6 and Chapter 7).

Lastly, the Rigor Cycle, aligned with the Communication stage of the DSRM, is mentioned in Section 7.9, where a scientific paper is presented. The Conclusions Chapter [8] also highlights the additions this work proposes to the knowledge base.

# Chapter 5

# Requirements

## 5.1 Methodology

To determine the requirements of a VR training platform that is effective, up-to-date, and user-friendly, this chapter outlines the structured research methodology employed. The methodology is based on a Systematic Literature Review (SLR), the evaluation of the quality of the selected studies, and structured data extraction. The insights derived from these steps directly address the three research questions defined in Chapter 3, and contribute to a requirements model and User Stories (US) for the proposed platform.

### 5.1.1 Systematic Review

To ensure a rigorous foundation, a Systematic Literature Review was conducted following established guidelines. This SLR aimed to collect, filter, and analyze relevant studies that discuss the characteristics of VR training platforms, Virtual Choreographies, and trainer integration.

#### 5.1.1.1 Research Questions

The following Research Questions (RQs), redefined in Section 3.2.5, guided the review:

- **RQ1:** *What characteristics are necessary in a VR training platform to provide an adequate and up-to-date training?*
- **RQ2:** *How can Virtual Choreographies be incorporated into a VR training platform to help industrial trainers understand user actions and create new courses?*
- **RQ3:** *How can a virtual training platform work with professional industrial trainers instead of attempting to replace them?*

#### 5.1.1.2 Search Strategy

A comprehensive set of search strings was developed using a refined list of keywords, derived from the thematic analysis (see Figure 3.6). Queries were executed on Scopus, combining concepts related to VR training, *Virtual Choreographies*, and trainer involvement, while filtering by publication year (post-2013) and excluding non-English and non-Portuguese results.

The search strings were built from the terms previously identified. However, this led to a short search string that was not specific enough to find relevant results. To solve this, some combinations of the terms from multiple RQ were used, as well as a refined version of the terms from RQ2, to provide more accurate and specific results.

Example query for RQ1 and RQ2 combined:

```
("Benefits of VR Training" OR "Characteristics of VR Training"
OR ...  )  AND ("Virtual Choreographies" OR "Sets of actions"
OR ...  )  AND (PUBYEAR > 2013) ...
```

Three main queries were used:

- RQ1 + RQ2
- RQ2 + RQ3
- Refined Virtual Choreographies (2020+)

#### 5.1.1.3 Selection Process

A total of **1970** papers were retrieved. After removing duplicates and conducting title and abstract screening, **93** papers were selected. Due to access limitations, **7** could not be obtained, leaving **86** for full-text review (Figure 5.1).

To manage the feasibility of the analysis, a filtering system using a custom AI-based classification assistant (ChatGPT with a customized configuration) was developed and employed. This assistant assessed the relevance of each paper on each of the three RQs, while providing justifications for its decisions. Papers classified as not relevant to all three RQs were excluded, resulting in **16** final papers used in this study.

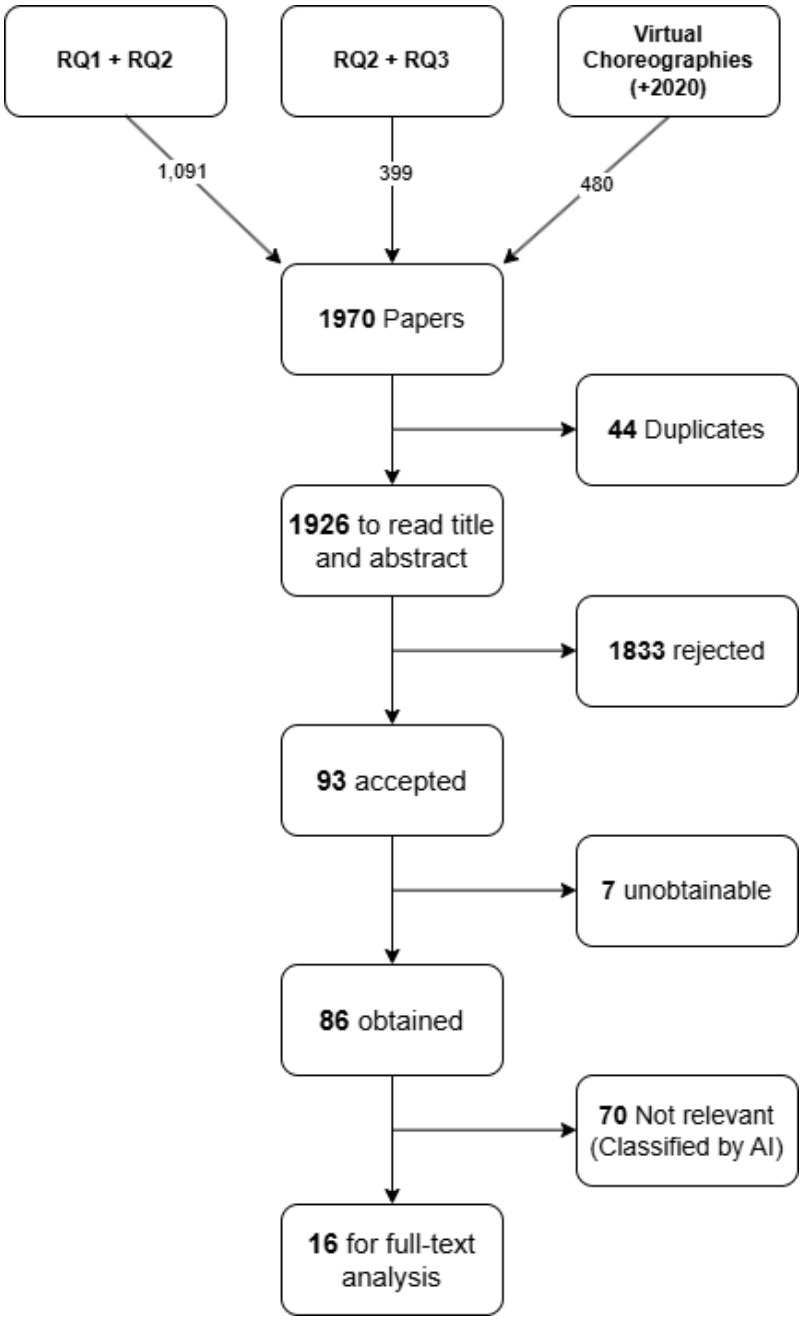



Figure 5.1: Diagram of the selection process.

#### 5.1.1.4 Classification of Relevant Papers

The AI assistant was trained with the research questions and a systematic workflow. Each paper was analyzed to determine:

- If it mentioned anything related to at least one RQ;
- Which RQs were mentioned;
- Specific excerpts supporting the classification;

- A final relevance score.

Only papers classified as relevant for all three research questions were retained for full extraction.

#### 5.1.1.5 Quality Assessment

To ensure the quality and consistency of the final 16 papers, a checklist was applied. Each study was assessed on:

- Realism of scenarios or tasks replicated in the study;
- Clarity in stating limitations;
- Inclusion of participant demographics;
- Definition of objectives;
- Detail in methods and evaluation;
- Metrics for training effectiveness;
- Description of the technology used;
- Adaptability and scalability;
- Use of *Virtual Choreographies* or structured workflows;
- Discussion of trainer roles.

This quality filter ensured that the extracted data was both reliable and contextually relevant.

#### 5.1.1.6 Data Extraction

A structured data extraction template was defined to capture critical attributes of the training platforms discussed in the literature. These included technical details, user experience elements, and evaluation criteria.

| **Description** | **Type** | **Values** |
|---|---|---|
| VR Training characteristics identified | String Field | n/a |
| Device type | Select Many Field | Augmented Reality, Desktop VR, Extended Reality, Mixed Reality, Mobile VR, Virtual Reality |
| Technology Used | Select Many Field | Custom Engines, Godot, Other, Unity, Unreal |

| Description | Type | Values |
|---|---|---|
| Devices Used | Select Many Field | HTC, HTC Vive, Oculus, Oculus Quest, Oculus Rift, Other, Valve Index |
| Training Domain/Industry | Select One Field | Construction, Education, Healthcare, Industrial Training, Military, Other |
| Training Focus | Select One Field | Cognitive Training, Other, Procedural Training, Safety Training, Skill Acquisition |
| Level of Immersion | Select One Field | HiVR, LiVR |
| Level of Fidelity | Select One Field | High-Fidelity, Low-Fidelity |
| Type of Interaction | Select Many Field | Controller-Based Interaction, Free-Hand Interaction, Gesture-Based Interaction, Touch-Based Interaction, Voice Interaction |
| Instructor Presence | Select One Field | High Presence, Low Presence, Moderate Presence, None |
| Content Authoring Capability | Boolean Field | n/a |
| Virtual Choreographies Integrated | String Field | n/a |
| Assessment Tools Integrated | Boolean Field | n/a |
| Adaptability to User Skill Level | Boolean Field | n/a |
| Collaboration Support | Boolean Field | n/a |
| Training Effectiveness Measured | Boolean Field | n/a |

Table 5.1: Data Extraction Form Fields.

Most of the elements described are objective in nature. However, the fidelity and level of immersion of a system are subject to interpretation.

For the level of immersion, two types of VR were considered: LiVR and HiVR (Lee and Wong 2014; Makransky, Terkildsen, and Mayer 2017), specifically, the simplified definitions from Kaplan-Rakowski and Gruber 2019 were considered - ‘We define LiVR as "a computer-generated three-dimensional virtual space experienced through standard audio-visual equipment, such as a desktop computer with a two-dimensional monitor"‘ and ‘We define HiVR as “a computer-generated 360° virtual space that can be perceived as being spatially realistic, due to the high immersion afforded by a head-mounted device”‘.

For the fidelity level, a system can be classified as either high-fidelity or low-fidelity. As defined by the authors, "High-fidelity VR systems should be able to present simulations with high-quality graphics and accurately track the users’ real bodies, therefore, providing a match between the human-sensory systems and VR systems" and "low-fidelity degree of visual realism

results from using low-quality 3D models in terms of geometry and textures, and it may result from aliasing in graphics" - Al-Jundi and Tanbour 2022.

#### 5.1.1.7 Synthesis

After the extraction and analysis, the characteristics and patterns revealed by the literature were synthesized to formulate coherent answers to each research question. These answers are detailed in the next section of this thesis.

## 5.2 Answers to the Research Questions

### 5.2.1 RQ1: What characteristics are necessary in a VR training platform to provide an adequate and up-to-date training?

The research identified several characteristics that a VR training platform must have to ensure an effective, adaptable, and up-to-date training. These characteristics are essential to allow the creation of immersive and engaging training experiences that can also be customized to suit evolving training needs.

#### 5.2.1.1 Ability to author content by trainers

A VR training platform should empower trainers with the ability to create, edit, and update training courses without the need for professional programming skills. This ensures that the training material remains relevant and can be adapted to evolving industry standards and procedures. The authoring tools should provide an intuitive interface that allows trainers to structure content effectively.

#### 5.2.1.2 Ability to rotate, position, and scale 3D objects

Trainers need to manipulate 3D objects within the virtual environment to design training scenarios accurately (Zarraonandia et al. 2016). This includes rotation, positioning, and scaling to customize the environment to match real-world conditions (Horst and Dörner 2019b; Brůža et al. 2021). Precise object handling allows for a better simulation of workspaces and enhances training realism.

#### 5.2.1.3 Adjustable perspective

An immersive training platform should allow users to adjust their viewpoint as needed during the simulation. This includes the ability to "fly" through the virtual environment. By providing users with this mechanic, we ensure that trainers can inspect training setups from multiple angles, improving course design and providing trainees with better visualization options (Brůža et al. 2021). Alongside this, trainees can also benefit from being able to view the environment in a more extensive way, which in many cases would not be possible in the real world. Drakos et al. 2021

showcases the importance of this aspect by allowing trainees to virtually access areas that are blocked by extreme radiation in the real world.

#### 5.2.1.4 Access to documentation mid-training

Providing trainees with access to documentation within the VR environment is an approach with great potential to enhance learning effectiveness (Cassola et al. 2021). Instead of having to leave the immersive space, trainees should be able to retrieve manuals, guides, or reference materials provided by the trainer directly within the simulation, reducing interruptions and improving knowledge retention. This method also improves the realism of the experience since, in many applications, trainees need to consult documents to help them learn. Despite being seen as a possible limitation by some authors (H. Coelho et al. 2024), the tool developed by Fernando Cassola et al. 2021 shows how it can be helpful for trainees.

#### 5.2.1.5 Record trainee and expert actions and voice

Recording actions and voice input from both trainers and trainees allows for post-training analysis and feedback (Fernando Cassola et al. 2021). This functionality enables trainers to review a trainee's actions, assess their performance, and provide targeted guidance. Additionally, trainees can replay expert demonstrations as 'ghosts' to reinforce learning (Wolfartsberger and Niedermayr 2020). This method also allows trainers to more accurately describe their actions and explain the procedures to the trainees in more detail, as well as allowing for contextualization of the tasks (Drakos et al. 2021).

#### 5.2.1.6 Use Virtual Choreographies to store user actions

*Virtual Choreographies* store user interactions at a higher semantic level, allowing actions to be recorded and later matched for analysis. This feature facilitates the review and assessment of training sessions by making it easier to identify errors or inefficiencies in task execution (Fernando Cassola et al. 2022).

#### 5.2.1.7 Replay actions as 'ghosts'

The ability to replay stored actions as 'ghosts' enhances training by allowing trainees to observe a trainer executing a specific task without having to leave the immersion of the virtual environment. This feature enables trainees to compare their performance with expert demonstrations, helping them understand what it is that they need to do (Wolfartsberger and Niedermayr 2020).

#### 5.2.1.8 Import and export resources and training courses

Interoperability is crucial for a VR training platform to maintain relevance. Trainers should be able to import or export existing resources (Ipsita et al. 2024). This includes 3D models, instructional

content, as well as complete training courses for reuse or sharing. This ensures that training modules can be easily updated and adapted (Horst et al. 2022).

#### 5.2.1.9 Standard file format for courses

To support compatibility across different platforms and applications, VR training courses should adhere to a standardized file format, such as XML (Zarraonandia et al. 2016). This facilitates content exchange between trainers, organizations, and third-party developers, ensuring longevity and reusability.

#### 5.2.1.10 Include pre-made examples of courses

Providing a library of pre-made training courses offers trainers a starting point for content creation (Horst et al. 2022). These examples serve as references or templates, accelerating the development of new training materials and ensuring consistency in course design.

#### 5.2.1.11 Include basic assets to serve as placeholders

Basic assets, such as generic machinery, tools, and environmental elements, should be available for trainers to use as placeholders. These help trainers build their courses quickly without needing to import custom assets immediately, allowing for a smoother authoring process. Another advantage is ensuring that the training experience is always ready to be tested and used during the authoring process (Horst and Dörner 2019b).

#### 5.2.1.12 Include tools to create courses

A basic set of authoring tools should be integrated within the VR training platform, allowing trainers to design, edit, and configure training modules efficiently (Horst et al. 2020). Features like drag-and-drop interfaces (Craven et al. 2024), employment of educational patterns (Horst and Dörner 2019a), and show-and-tell patterns (Horst et al. 2020) enhance usability.

#### 5.2.1.13 Combine VR and non-VR

VR and non-VR methods have benefits and drawbacks, and they can complement each other. The training platform should support both VR and non-VR modes (Horst et al. 2022), allowing trainers to create content on desktop environments before refining it in VR. Desktop solutions are perceived as easier to use and more precise (Zarraonandia et al. 2016), while VR solutions offer greater immersion (Horst et al. 2020). This hybrid approach reduces fatigue associated with prolonged VR usage (Zarraonandia et al. 2016) and provides flexibility in content development.

#### 5.2.1.14 Desktop to start creation of courses

Initial authoring should be feasible on a desktop, allowing trainers to structure course content, input text, define learning objectives, and place assets efficiently before transitioning to VR for final adjustments (Zarraonandia et al. 2016).

#### 5.2.1.15 VR to refine courses and practice procedures

Once a course is structured on a desktop, trainers should be able to refine and test the training experience in VR. This step ensures that the virtual environment resembles real-world conditions and provides an immersive, accurate simulation (Horst et al. 2022).

#### 5.2.1.16 Text inputs in desktop, not in VR

Text input, such as labeling objects or writing instructions, should be done primarily on a desktop to avoid the hardships of using virtual keyboards (Horst et al. 2020). This allows for a faster and more comfortable content creation experience, while maintaining VR immersion for practical training and preventing users from repeatedly putting on and removing their VR headset (Horst et al. 2022).

#### 5.2.1.17 Ability to import 3D models and CAD data

A VR training platform should allow users to import their own 3D models and CAD data. This improves the quality of the experience created and ensures the accuracy and quality of the models used, making them closer to the real-world objects they represent. This ensures that training scenarios are as realistic and industry-relevant as possible. This feature is very much present in the literature and mentioned by several authors (Fernando Cassola et al. 2021; Fernando Cassola et al. 2022; Cassola et al. 2021; Horst and Dörner 2019b; Brůža et al. 2021).

#### 5.2.1.18 Create a similar experience for trainers and trainees

To ensure high-quality training, the training platform should provide trainers, especially those authoring content, a similar experience to the one their trainees will experience (Zarraonandia et al. 2016). This involves allowing the trainer to practice on their created courses exactly like a trainee would.

#### 5.2.1.19 Allow for direct contact and communication between trainer and trainee in the virtual environment

Learning is not always an individual process, therefore, direct communication with a trainer, such as using a voice channel, could be useful to improve the immersion of the experience and gain significant feedback (Brůža et al. 2021).

A built-in communication system should allow trainers and trainees to interact seamlessly within VR. Voice chat, annotations, and shared environments could enhance collaboration and ensure that trainers can guide trainees effectively.

#### 5.2.1.20 Divide training content into smaller and reusable chunks

Training modules should be structured into smaller, reusable segments, or "VR Nuggets" (Horst and Dörner 2019a). This modular approach allows for incremental learning, flexibility in training design, and efficient content updates (Horst and Dörner 2019b).

#### 5.2.1.21 Interoperability of devices

The training platform should be compatible with various VR headsets and input devices, ensuring accessibility across different hardware configurations (Horst and Dörner 2019b). This reduces dependency on specific manufacturers and broadens the user base.

#### 5.2.1.22 Different types of movement (continuous and teleport)

To accommodate different user preferences and avoid motion sickness, the VR training platform should support multiple movement options, including continuous movement and teleportation (Brůža et al. 2021). This flexibility enhances accessibility and usability.

#### 5.2.1.23 Accessible to a wide range of users

A VR training platform should prioritize accessibility by considering factors such as user interface simplicity, compatibility with assistive technologies, and customizability for different user needs (H. Coelho et al. 2024). This ensures inclusivity and maximizes usability across diverse demographics (Craven et al. 2024).

### 5.2.2 RQ2: How can virtual choreographies be incorporated in a VR training platform to help industrial trainers understand user actions and create new courses?

*Virtual Choreographies* can be a crucial tool in VR training platforms by allowing the recording and storage of user actions at a higher semantic level (Fernando Cassola et al. 2022). They define actions within a meaningful contextual framework, making them easier to analyze, compare, and repurpose, unlike traditional methods that rely on raw data (Fernando Cassola et al. 2021).

An advantage of using *Virtual Choreographies* is their ability to match the actions of trainers and trainees, helping in finding what is being done right and what can be further improved (Fernando Cassola et al. 2021; Fernando Cassola et al. 2022).

Similarly to the way *Virtual Choreographies* can be used to match actions, they can also be used to store trainers' actions to be then used as a 'ghost' replay for trainees to accurately see what actions they need to perform (Wolfartsberger and Niedermayr 2020).

Instead of designing every new training course from scratch, choreographed action sequences can be used to develop training courses by leveraging pre-recorded movement sequences to create adaptable training scenarios (Ipsita et al. 2024).

These choreographies can be used to create standard configuration files that structure training modules within the VR platform (Ipsita et al. 2024). This standardization allows for a simple and easy integration of training resources to create adaptable experiences. These configuration files also allow training courses to be easily shared among trainers and empower them to make small changes very efficiently (Zarraonandia et al. 2016; Brůža et al. 2021; H. Coelho et al. 2024).

### 5.2.3 RQ3: How can a virtual training platform work with professional industrial trainers instead of attempting to replace them?

If the role of trainers is not properly addressed in virtual training platforms, they might be poorly received by experts, which could lead to their lack of support. Without trainers, a training platform quickly loses value, and the literature clearly indicates that learning is much more effective when a trainer is present in the training (Fernando Cassola et al. 2021). This way, trainers need to be incorporated by giving them control over the authoring of training content and also allowing them to easily update this content to keep it up-to-date.

Trainers should also be able to use the virtual environment to physically demonstrate procedures that can also be recorded and played back by trainees (Fernando Cassola et al. 2021; Wolfartsberger and Niedermayr 2020). In this sense, recording user actions allows trainees to see how a procedure should be done and allows trainers to see what their students are doing right or wrong and provide feedback accordingly (Cassola et al. 2021). Collaboration is also an important aspect of learning, and experts should have the ability to share resources and improve on others' work to progress the overall quality of training (Ipsita et al. 2024). Collaboration between trainers could also be used to provide better feedback to trainees (Fernando Cassola et al. 2022).

Lastly, it could also be very beneficial for the effectiveness of training, a direct interaction between trainer and trainee inside the virtual environment without the need to break the immersion (Brůža et al. 2021).

## 5.3 Actors

In this thesis, three types of actors were considered, present in table 5.2. The work revolves around the interactions and properties of Trainers and Trainees, both of which have some similar features and are, therefore, instances of the User actor.

| Identifier | Description |
|---|---|
| User | Generic user that accesses the platform. |
| Trainer | User who can access the authoring feature to create content. |
| Trainee | User who uses the platform to acquire knowledge. |

Table 5.2: Actors and their descriptions.

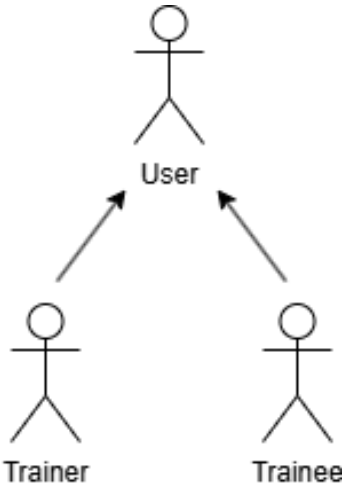



Figure 5.2: Actors.

## 5.4 Requirements

### 5.4.1 Functional Requirements

The following functional requirements in Table 5.3 were derived from the key characteristics and specifications identified in the research process. They define the essential capabilities needed to support high-quality authoring, training, interaction, and content management within the system.

| Identifier | Name | Description |
|---|---|---|
| FR01 | Authoring | The system should allow trainers to author content. |
| FR02 | Object Handling | The system should allow users to rotate, position, and manipulate objects. |
| FR03 | Adjustable POV | The system should provide adjustable perspectives for better visualization. |
| FR04 | Documentation | The system should allow users to access documentation. |
| FR05 | Action Recording | The system should record trainee and expert actions for future reference. |
| FR06 | Action Storage | The system should allow users to store actions using Virtual Choreographies. |
| FR07 | Action Replay | The system should enable the replay of stored actions as "ghosts." |
| FR08 | Import/Export | The system should support importing and exporting training courses and resources. |
| FR09 | Pre-made Examples | The system should include pre-made examples of training courses. |
| FR10 | Asset Placeholders | The system should include basic assets that can serve as placeholders. |
| FR11 | Authoring Tools | The system should provide tools for trainers to create courses. |
| FR12 | VR and Non-VR Mix | The system should support a combination of VR and non-VR training. |
| FR13 | Desktop Authoring | The system should allow course creation on a desktop. |
| FR14 | VR Authoring Refinement | The system should allow course refinement. |
| FR15 | VR Practice | The system should allow procedure practice in VR. |
| FR16 | Desktop Text Input | The system should allow text input on desktop and not in VR. |
| FR17 | Communication | The system should provide a communication mechanism between trainers and trainees in the virtual environment. |
| FR18 | VR Nuggets | The system should allow training content to be divided into smaller and reusable chunks. |
| FR19 | Movement Types | The system should support different movement types (continuous and teleport). |

Table 5.3: Functional Requirements.

### 5.4.2 Non-Functional Requirements

The non-functional requirements present in Table 5.4 focus on the system's overall quality, usability, and performance. They ensure a seamless, accessible, and efficient experience across various devices and platforms.

| Identifier | Name | Description |
|---|---|---|
| NFR01 | Experience Equality | The system should ensure a similar experience across devices. |
| NFR02 | Accessibility | The system should be accessible to a wide range of users. |
| NFR03 | Usability | The system should be simple and easy to use. |
| NFR04 | Performance | The system should run with a framerate no lower than 60 FPS. |
| NFR05 | Compatibility | The system should be compatible with major VR platforms. |

Table 5.4: Non-Functional Requirements.

### 5.4.3 Technical Requirements

The following technical requirements in Table 5.5 were identified based on the design and implementation needs of the system. They ensure compatibility, interoperability, and support for essential hardware and software components, enabling a functional and scalable solution.

| Identifier | Name | Description |
|---|---|---|
| TR01 | Standard File Format | The system should support a standard file format. |
| TR02 | Asset Import | The system should support the import of 3D models. |
| TR03 | Interoperability | The system should support interoperability across platforms. |
| TR04 | Hardware Compatibility | The system should support VR headsets, motion controllers, etc. |
| TR05 | VR SDK Compatibility | The system should be developed using Unity3D with VR SDKs. |

Table 5.5: Technical Requirements.

## 5.5 User Stories

User stories capture the functionality of the system from the perspective of its actors, ensuring that development is aligned with their needs. These stories define key actions and expectations, classify the respective implementation effort, and prioritize features that enhance the experience for all actors.

Table 5.6 displays these user stories ordered by priority.

| Identifier | Name | Priority | Size | Description |
|---|---|---|---|---|
| US01 | Authoring | Very High | XL | As a Trainer, I want to be able to author training courses and modify existing ones so that I can customize courses and keep them up-to-date. |
| US02 | Adjust Objects | Very High | L | As a Trainer, I want to be able to rotate, position, and scale 3D objects during the authoring process so that the course is fully customized. |
| US03 | Adjustable POV | High | L | As a Trainer, I want to be able to adjust my perspective and "fly" in the VE so that I can see the entire scene in detail. |
| US04 | Documentation | High | L | As a Trainer, I want to upload documentation that the trainees may require, so that they have the necessary tools available to them. |
| US05 | Documentation Selection | Medium | M | As a Trainer, I want to choose when the Trainee can access a specific document during the training, so that they are not overwhelmed. |
| US06 | Documentation Access | Medium | M | As a Trainee, I want to be able to access the documentation provided by the Trainer during the practice, so that I have all the tools I need. |
| US07 | Record Trainer Actions | Very High | XL | As a Trainer, I want to be able to record my actions (head and hand movement) in the practice phase so that I can demonstrate how a procedure should be done. |
| US08 | Record Trainer Voice | Low | S | As a Trainer, I want to be able to record my voice during practice so I can better guide any Trainee. |
| US09 | Record Trainee Actions | Very High | L | As a Trainee, I want to record my actions during a practice procedure so that a Trainer can see exactly what I am doing. |
| US10 | Record Trainee Voice | Low | S | As a Trainee, I want to record my voice during a practice procedure so I can explain my actions and speak to my instructor. |

| Identifier | Name | Priority | Size | Description |
|---|---|---|---|---|
| US11 | Storing Actions | High | L | As a Trainer, I want to store actions using Virtual Choreographies so that I can easily understand what they mean without needing a complex understanding of the environment. |
| US12 | Trainer Action Replay | High | L | As a Trainer, I want to replay Trainee actions as a 'ghost' in VR so that I can accurately see what they are doing and provide feedback. |
| US13 | Trainer Action View | High | M | As a Trainee, I want to replay the Trainer actions in VR so that I can see how a specific procedure should be done. |
| US14 | Content Import | Medium | M | As a Trainer, I want to import existing training courses so that I can access them and, if needed, modify them. |
| US15 | Content Export | Medium | S | As a Trainer, I want to export training courses so that I can share them with other trainers. |
| US16 | Standard Course Format | Medium | M | As a Trainer, I want to have a single standard file format for courses so that it is simple to exchange them. |
| US17 | Pre-made Examples | High | M | As a Trainer, I want to have pre-made examples in the authoring process so that I can have a starting point or see how things could be done. |
| US18 | Placeholders | High | S | As a Trainer, I want to have basic assets to serve as placeholders in the authoring process so that the course does not look empty and hard to understand. |
| US19 | Desktop Authoring | Low | M | As a Trainer, I want to start the authoring process in Desktop mode so that I do not spend too much time in VR, leading to exhaustion. |
| US20 | VR Authoring | Very High | M | As a Trainer, I want to finish the authoring process in VR so that I can better see how the course is put together and make final changes. |
| US21 | Trainer VR Practice | High | M | As a Trainer, I want to use the platform to practice on the courses I created or existing ones, so that I can assess if changes need to be made. |

| Identifier | Name | Priority | Size | Description |
|---|---|---|---|---|
| US22 | Trainee VR Practice | High | M | As a Trainee, I want to freely practice procedures in VR, created by trainers, so that I can improve on the procedures trained. |
| US23 | Non-VR Text Inputs | Low | S | As a Trainer, I want to fill all my text inputs on desktop rather than VR, so that I do not use virtual keyboards. |
| US24 | Asset Import | Very High | S | As a Trainer, I want to be able to import my own 3D models and CAD data in various formats so that I can use them in my courses. |
| US25 | Asset Placement | Very High | M | As a Trainer, I want to incorporate my own assets into the course so that I can ensure a high-quality environment. |
| US26 | Collaborative Training | Low | XL | As a User, I want to enter a practice procedure with another User so that we can share experiences and receive direct help. |
| US27 | VR Communication | Low | M | As a User, I want to be able to speak to another User inside my training procedure. |
| US28 | VR Nuggets | High | S | As a Trainer, I want to divide a training course into smaller steps and phases (modules and sections) so I can better structure the learning process. |
| US29 | Interoperability | Very High | S | As a User, I want to be able to use different headsets to access the platform so that compatibility is not an issue. |
| US30 | Movement Types | High | S | As a User, I want to be able to use both continuous movement and teleportation in VR so that I can choose the best method for me. |
| US31 | Ease of Use | Very High | M | As a User, I want to not need software development skills to use the platform. |
| US32 | Matching Actions | Medium | L | As a Trainer, I want to have the Trainee actions matched with my own so I can quickly see what they are doing right or wrong. |
| US33 | Visual Display | High | S | As a Trainer, I want the trainees to see my avatar's hand position so I can show them things and improve the interaction in the collaboration mode. |

| Identifier | Name | Priority | Size | Description |
|---|---|---|---|---|
| US34 | Resource Sharing | Low | L | As a Trainer, I want to use the desktop mode to collaborate with other experts. |
| US35 | Action Ordering | Very High | M | As a Trainer, I want to be able to define an order in which actions need to be taken so that I can define the procedure. |
| US36 | Action Ordering Specification | Very High | M | As a Trainer, I want to define actions in which the order does not matter, so that some tasks do not get overcomplicated. |

Table 5.6: User Stories, ordered by priority.

# Chapter 6

# First Prototype

## 6.1 Introduction

This chapter presents the first prototype developed as part of this thesis. The main goal of this iteration was to create the foundation of the platform being researched and establish core functionalities needed to support immersive and authorable VR training environments. The features implemented were based on the requirements defined in Chapter 5, and the prototype serves as a proof of concept to validate interactions, environment generation, and basic authoring tools.

## 6.2 Development Context

The development of the first prototype was carried out using Unity, selected for its versatility, cross-platform VR support, and a robust development ecosystem with an active community and plugin availability. The Unity version 6.0 was also selected since, even though it is quite recent at the time of writing this thesis, it is state-of-the-art for VR development, and the platform to be developed should keep up with the current VR scene. Initially, the implementation used a combination of two systems for managing VR interactions and input: the SteamVR plugin and the XR Interaction Toolkit.

### 6.2.1 SteamVR vs. XR Interaction Toolkit

SteamVR was originally considered due to its early support for high-end headsets (e.g., HTC Vive) and its powerful input system. This choice was also inspired by the platform developed by Fernando Cassola et al. 2021, which contained many features intended for the platform explored in this thesis. However, as development progressed, several technical and maintenance issues surfaced:

- **Deprecated System:** SteamVR, despite all its functionalities, has yet to provide an update since Unity 6.0 came out, making it slightly outdated and some of its features redundant.

The platform to be developed should be able to keep up with the changes in the XR scene, and SteamVR was not reflecting that.

- **Conflicting Input Systems:** SteamVR and XR Interaction Toolkit each implement their own input and interaction systems, leading to input conflicts and device handling inconsistencies. This also meant that future changes to the platform would be much more difficult.
- **Conflicting Plugins:** Similar to the previous item, SteamVR uses the OpenVR plugin while XR Interaction Toolkit benefits from using the OpenXR plugin. This difference, despite seeming small, causes several issues and complications that add up during development.
- **Compatibility Concerns:** The SteamVR plugin, while powerful, had limited out-of-the-box support for newer Unity XR standards, making future maintenance and extensibility more difficult.
- **Lack of Integration:** Unity is increasingly focusing on its native XR Plugin Management system, which works seamlessly with the XR Interaction Toolkit. This made XR Toolkit a more future-proof choice.
- **Simplified Setup and Support:** The XR Interaction Toolkit provided a more integrated experience with Unity's XR Management pipeline, easier setup, and documentation that matched the evolving Unity workflow.

Due to these factors, a decision was made to remove SteamVR entirely and consolidate the system around Unity's XR Management system and XR Interaction Toolkit, version 3.1.1. This switch improved stability, simplified the codebase, and ensured better long-term device interoperability.

### 6.2.2 Asset Loading and CAD Integration

In this early prototype, asset loading was limited to Unity prefabs that were manually created and placed in the project's resource folder. Although full support for importing external assets, such as CAD files, is expected in a later version of the desired platform, it was not fully implemented in this iteration for the following reasons:

- **Time Constraints:** Implementing runtime model loading - especially from CAD or industrial file formats - involves nontrivial integration work, including parsing, mesh conversion, and optimizing materials. All of which fall outside of the objective of this thesis.
- **Format Complexity:** CAD files often use proprietary or heavy formats (e.g., STEP, IGES, or STL) that require external libraries or intermediate processing tools to convert them to Unity-supported formats like '.fbx' or '.obj'.
- **Runtime Performance Concerns:** Ensuring acceptable performance when loading and rendering complex 3D models in VR - especially without freezing the application - requires

asynchronous loading and mesh optimization pipelines, which were beyond the scope of this first version.

- **Developer Skill Independence Goal:** Ultimately, the platform is intended for non-developers to use. A robust and user-friendly CAD importer would require a UI layer and error-handling mechanisms that would only make sense for a future iteration.

As such, this version relies on pre-built prefabs for demonstration purposes. These prefabs only provide the basis of the object to be rendered, meaning they only have the mesh and the mesh renderer components. All of the remaining components for physics and interactions are added at runtime by the system. Nevertheless, the system's architecture was designed to accommodate runtime asset loading in future versions with support for external 3D content.

## 6.3 Different Modes of Execution

The system requires a few different functionalities and, to better accommodate them, the configuration file specifies which of the four possible modes the program should be executed in. The modes differentiate whether the system is being run by a trainer or a trainee, and also the types of tasks they will be performing.

### 6.3.1 Authoring Mode

The authoring mode is where the trainer will create and customize the training environment (Figure 6.1) and set up the objects for the procedures the trainees will need to replicate.

It should provide the most freedom and contain tools users can rely on to create realistic scenarios using their own models. Despite not fully implemented in this first prototype it is intended to allow trainers to create a show and tell course for trainees to identify different parts of a system or machine, as well as a procedural course where trainers specify which parts trainees will have to interact with, the order of this interaction and whether or not they will have specific drop zones for these parts.

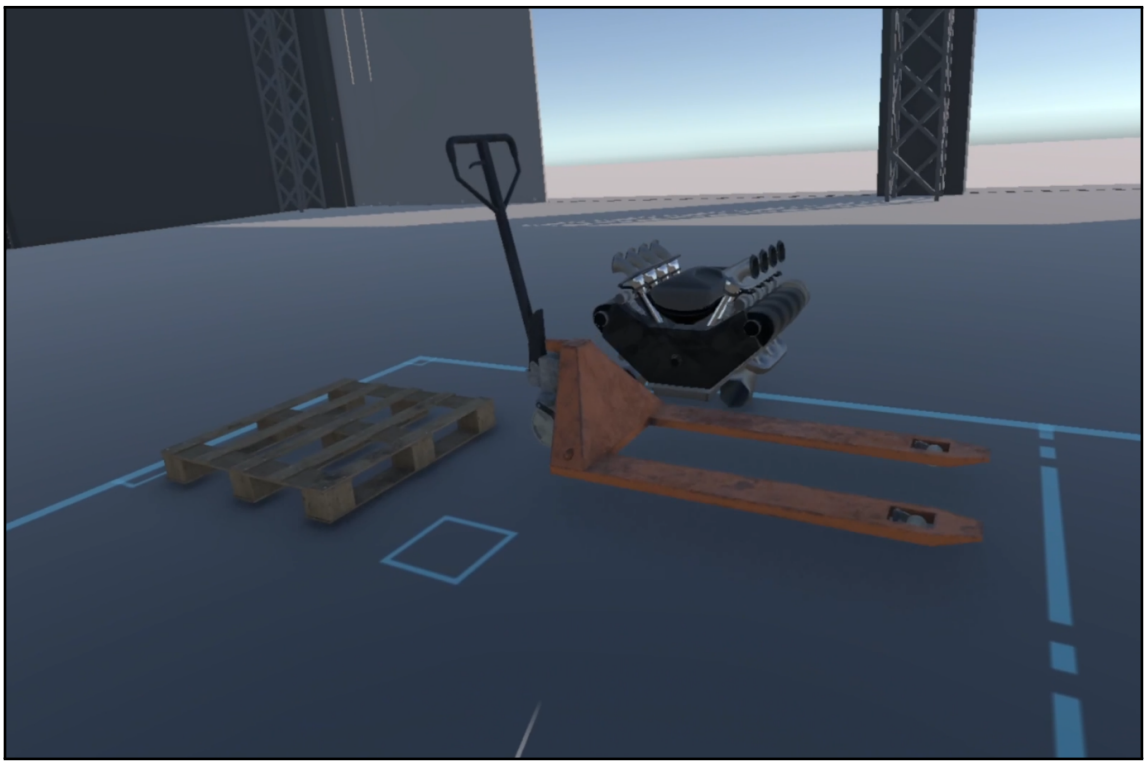


Figure 6.1: Environment example.

### 6.3.2 Practice Mode

The practice mode is where the trainees can experience a previously created training scenario. They will have the opportunity to practice a course multiple times without cost and commit errors without consequences.

In this mode, trainees will be able to play recordings of the trainer performing certain tasks and attempt to replicate them to the best of their abilities. Although not present in this prototype, this mode should also allow access to the documentation provided by the instructors.

### 6.3.3 Replay Mode

The replay mode is a simpler scene of the training environment where trainers can choose and visualize recordings of a trainee attempting a procedure. This visualization can be used to allow for evaluation and feedback. This mode grants an improved presence of trainers in the education process and gives them the opportunity to follow their students more closely.

### 6.3.4 Trainer Test Mode

The trainer test mode merges the features of the practice and authoring modes. It is intended for trainers and allows them to practice and experiment with the course they created, all while allowing for small changes to be performed without having to change modes or scenes. It should

streamline the course development process and give trainers a similar sense of experience to the one their students will encounter.

In this mode, they will be able to define training procedures step by step.

## 6.4 Features Implemented

The first prototype implements a subset of the features identified in the requirements analysis and research findings. These include both user interaction functionalities and basic authoring capabilities.

### 6.4.1 Movement and Navigation

Users can move within the virtual environment using two main methods: continuous movement and teleportation (Figure 6.2). To improve comfort and reduce motion sickness, snap-turn functionality is also available. Furthermore, a "grab move" mechanic allows users to grab and hold their virtual hand in place to displace their body, effectively enabling them to 'fly' and view the scene from elevated or unreachable angles. This feature is extracted from the literature and is particularly useful for understanding the layout of complex training scenarios or aiding in course authoring.

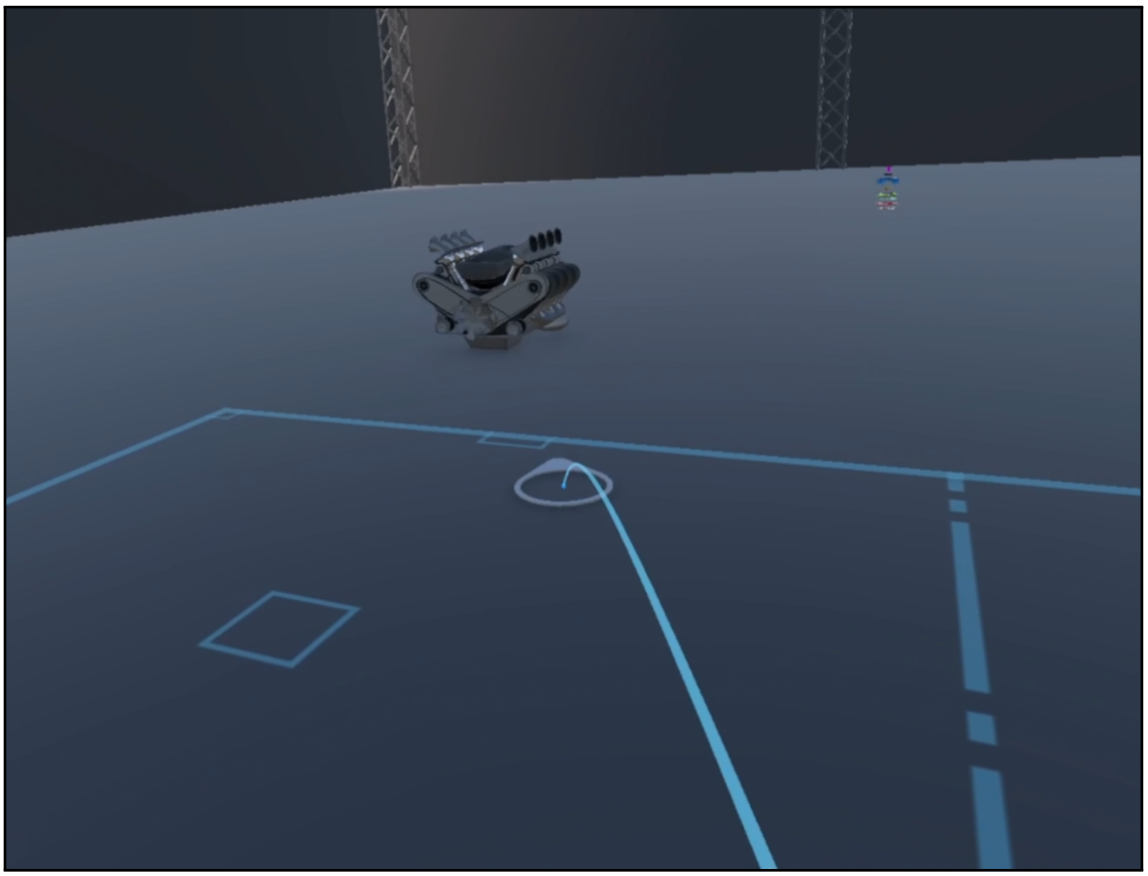


Figure 6.2: Teleport movement.

### 6.4.2 Environment Setup and Configuration

A JSON configuration file serves as the basis for constructing the virtual environment. It includes specifications for the environment's layout, object types, spawn points, details on the current training scenario, and other scene-related parameters. At runtime, this file is parsed, and the virtual training scene is dynamically built based on its contents. The use of a configuration file allows for an external platform or web interface to make small changes in the training scenario without the need to put on a VR headset. It also allows users to avoid using virtual keyboards, which are seen by many studies as a limitation (Fernando Cassola et al. 2021) since any text needed can come directly from the configuration file.

### 6.4.3 Authoring Tools and User Menu

A built-in radial option menu allows users to access multiple features of the platform, as seen in Figure 6.3.

The authoring mode focuses on providing a simple and accessible interface for non-technical users, such as industrial trainers.

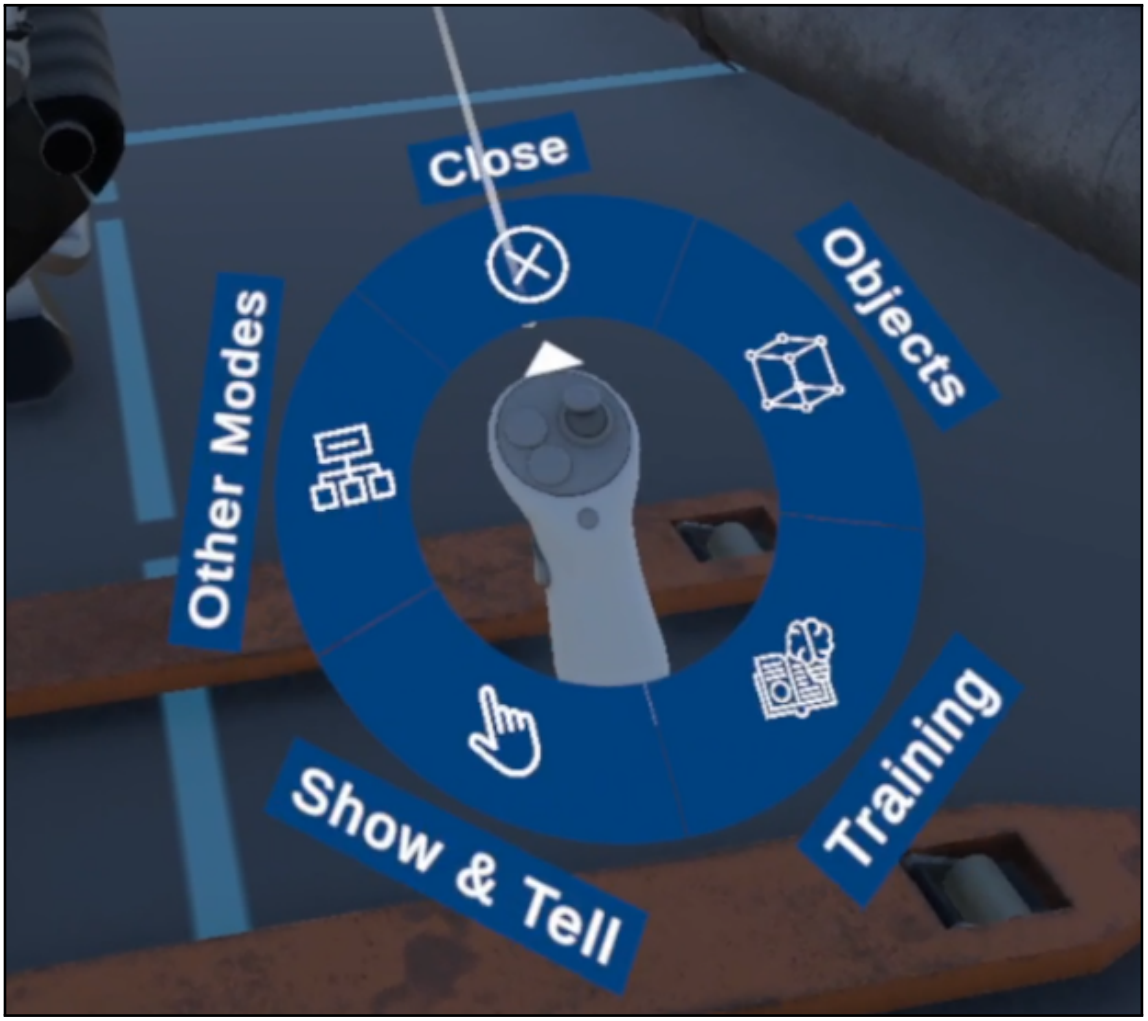



Figure 6.3: Environment example.

#### 6.4.3.1 Set the trainee spawn point

To define where the trainee starts the training procedure, the trainer can configure a spawn point using an option from the menu (6.4). This starting position is then saved in the configuration file to be used later.




Figure 6.4: Setting the spawn point.

#### 6.4.3.2 Select and import objects into the scene

To customize the experience and improve the realism of the environment, the platform allows users to place props (6.5), decorative objects with physics, and interactables, objects with no physics and rigged for immersive interaction.

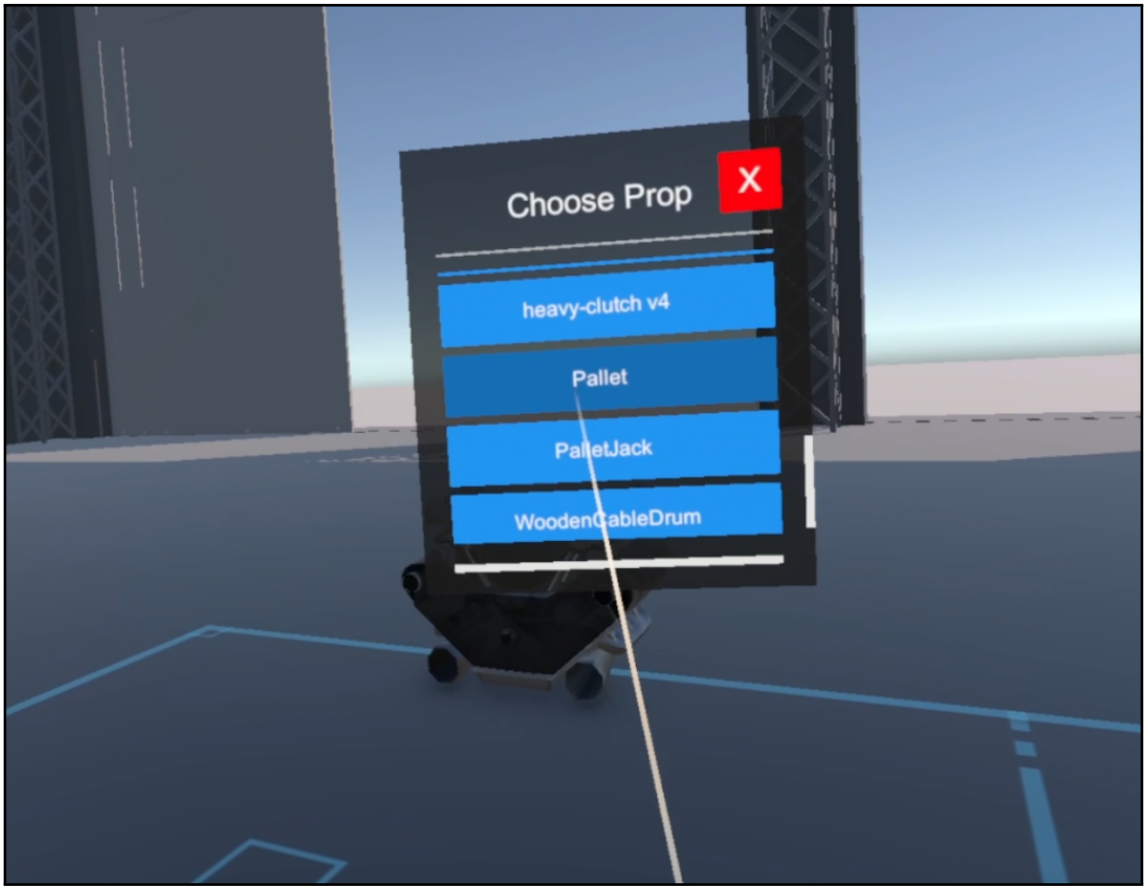



Figure 6.5: Importing props.

#### 6.4.3.3 Edit the scene

Just as objects are added and placed, there is also a need to be able to edit their position and reconfigure a preexisting scene.

#### 6.4.3.4 Switch between different modes

The menu also allows the user to switch between the different modes (Trainer Test, Authoring, Replay, and Practice).

### 6.4.4 Object Manipulation

Once in the VR environment, users can place and manipulate objects. The prototype allows for the following:

- Import of props and interactable objects from a list of available prefabs (Figure 6.6);
- Adjustment of the object's scale, position, and rotation (Figure 6.7);
- For interactable objects the system adds all Unity components necessary to apply physics and interactions (Figure 6.8);

- For complex interactable objects, the system allows users to deconstruct them piece by piece (e.g., disassembling an engine, Figure 6.9).

These functions enable trainers to customize their training environments without the need for programming knowledge.

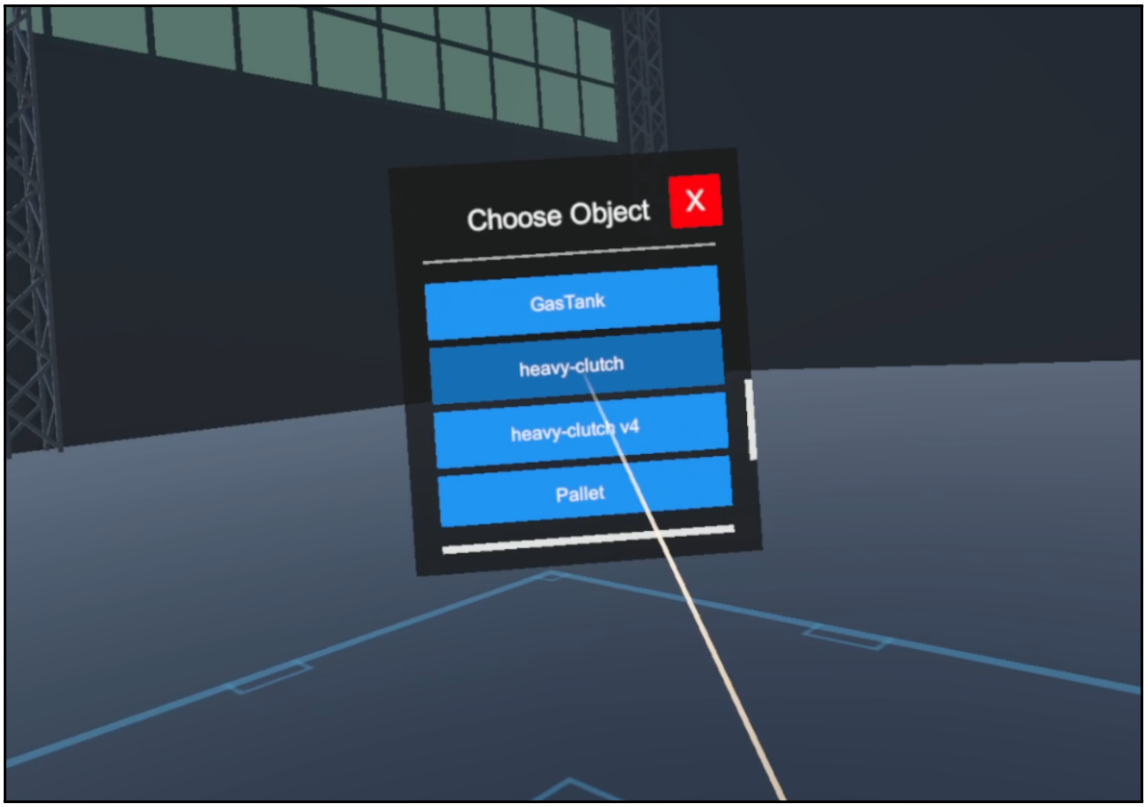



Figure 6.6: Importing interactable objects.



Figure 6.7: Adjusting scale of imported objects.



Figure 6.8: Interaction with objects.

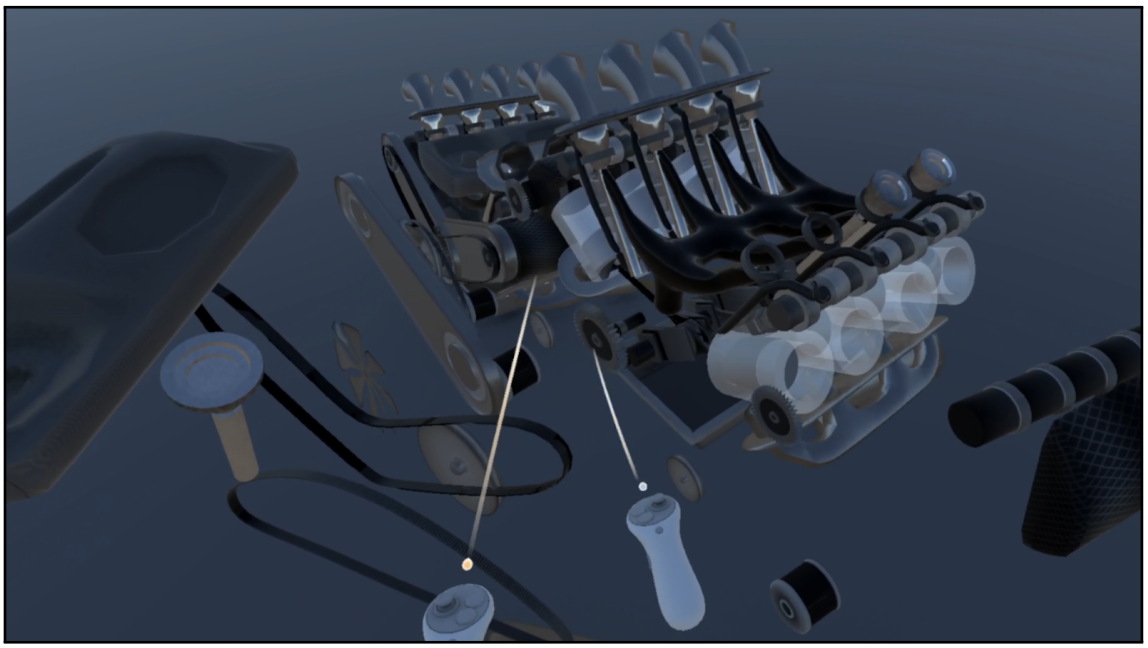


Figure 6.9: User disassembling a car engine.

## 6.5 Demonstration

The state of the first prototype, alongside the respective documentation, was also showcased in video format, more precisely, a video published on YouTube (Ferreira 2025a, Figure 6.10). This video shows most of the features implemented and serves as an accurate representation of the system developed.

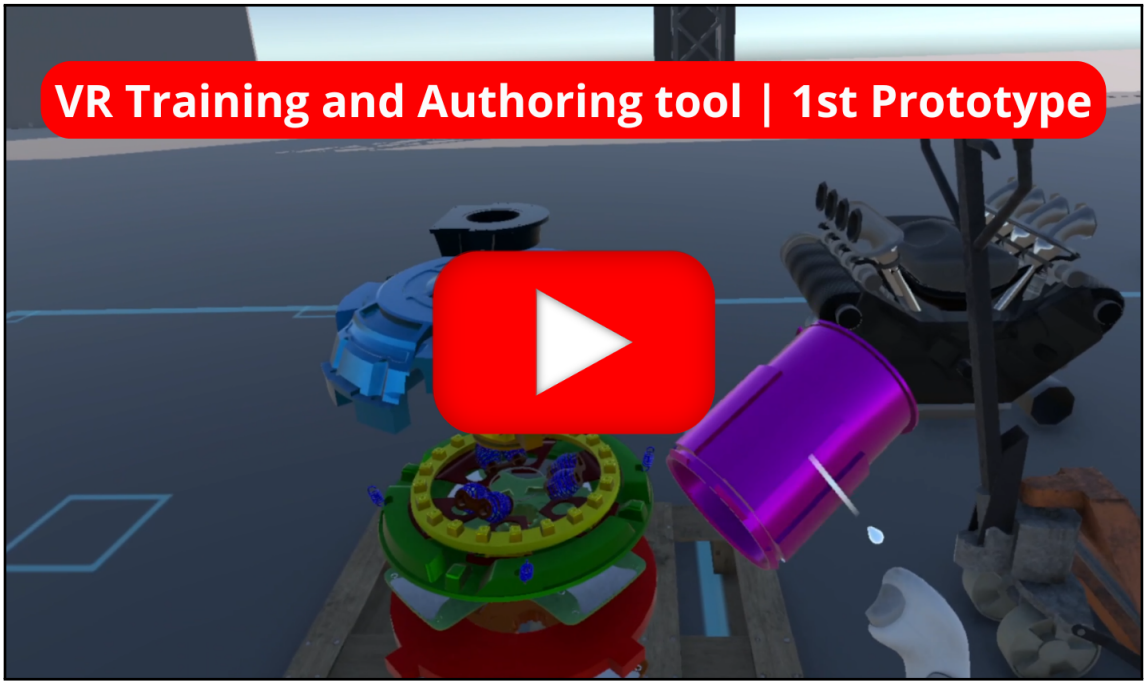



Figure 6.10: Thumbnail of the YouTube video demo of the first prototype.

## 6.6 Evaluation

### 6.6.1 Methodology

The evaluation of the first prototype followed a qualitative and requirements-driven approach. Its goal was to verify how well the implemented features aligned with the defined user stories and identify limitations and areas for future improvement. The process was divided into two primary steps:

#### 6.6.1.1 User Story Validation

The user stories outlined in Chapter 5 were used as the primary reference to assess functional coverage. Each story was reviewed individually and assigned a subjective percentage of completeness based on whether the functionality it described was:

- Fully implemented;
- Partially implemented;
- Not implemented.

This estimation was conducted manually through feature inspection and prototype walkthroughs. The results were then compiled into a color-coded table (Table 6.1) to provide a visual overview of implementation progress. While the percentages are not quantitatively measured, they provide an informative estimate of the state of the prototype and development priorities.

#### 6.6.1.2 Informal User Testing

To complement the internal evaluation, a set of informal tests were conducted with a small group of peers from the university. These sessions were unstructured and focused primarily on usability and first impressions. Participants were asked to interact with the prototype in VR with no prior explanation and provide spontaneous feedback on the experience (some tips were later given as needed). The goal was not to perform statistical analysis but rather to gather anecdotal evidence and early indicators of interface strengths and weaknesses.

Participants were encouraged to comment on the intuitiveness of controls, comfort during use, and potential barriers to completing tasks. Their feedback was noted and summarized in Section 6.6.4 as part of the system assessment. This feedback loop was especially important given the target audience for the system (non-technical domain experts), whose needs might differ significantly from those of experienced VR developers.

### 6.6.2 User Story Coverage

To assess the completeness of the prototype, the list of user stories defined in Chapter 5 was revisited. Each story was reviewed to determine whether the current prototype implemented it, either fully or partially. These were then evaluated using a subjective estimation of implementation completeness.

The analysis showed that the prototype satisfies approximately **35%** of the defined user stories. Although this is a partial implementation, it provides a strong foundation for iterative development.

| ID | Name | % Done | ID | Name | % Done |
|---|---|---|---|---|---|
| US01 | Authoring | 70 | US19 | Desktop Authoring | 100 |
| US02 | Adjust Objects | 100 | US20 | VR Authoring | 60 |
| US03 | Adjustable POV | 100 | US21 | Trainer VR Practice | 60 |
| US04 | Documentation | 10 | US22 | Trainee VR Practice | 50 |
| US05 | Documentation Selection | 5 | US23 | Non-VR Text Inputs | 100 |
| US06 | Documentation Access | 5 | US24 | Asset Import | 100 |
| US07 | Record Trainer Actions | 5 | US25 | Asset Placement | 100 |
| US08 | Record Trainer Voice | 0 | US26 | Collaborative Training | 0 |
| US09 | Record Trainee Actions | 0 | US27 | VR Communication | 0 |
| US10 | Record Trainee Voice | 0 | US28 | VR Nuggets | 0 |
| US11 | Storing Actions | 0 | US29 | Interoperability | 100 |
| US12 | Trainer Action Replay | 0 | US30 | Movement Types | 100 |
| US13 | Trainer Action View | 0 | US31 | Ease of Use | 60 |
| US14 | Content Import | 80 | US32 | Matching Actions | 0 |
| US15 | Content Export | 80 | US33 | Visual Display | 0 |
| US16 | Standard Course Format | 80 | US34 | Resource Sharing | 0 |
| US17 | Pre-made Examples | 50 | US35 | Action Ordering | 50 |
| US18 | Placeholders | 100 | US36 | Action Ordering Specification | 50 |

Table 6.1: User Story Coverage in the First Prototype.

### 6.6.3 Requirements Coverage

To complement the user story assessment, the functional, non-functional, and technical requirements defined in Chapter 5 were revisited and analyzed based on their implementation status in the first prototype. Each requirement was assigned a subjective completeness percentage to reflect its current state. Tables 6.2, 6.3, and 6.4 summarize this assessment.

#### 6.6.3.1 Functional Requirements Coverage

| ID | Name | Completeness (%) |
|---|---|---|
| FR01 | Authoring | 70 |
| FR02 | Object Handling | 100 |
| FR03 | Adjustable POV | 90 |
| FR04 | Documentation | 5 |
| FR05 | Action Recording | 0 |
| FR06 | Action Storage | 20 |
| FR07 | Action Replay | 0 |
| FR08 | Import/Export | 50 |
| FR09 | Pre-made Examples | 10 |
| FR10 | Asset Placeholders | 100 |
| FR11 | Authoring Tools | 5 |
| FR12 | VR and Non-VR Mix | 100 |
| FR13 | Desktop Authoring | 0 |
| FR14 | VR Authoring Refinement | 0 |
| FR15 | VR Practice | 5 |
| FR16 | Desktop Text Input | 100 |
| FR17 | Communication | 0 |
| FR18 | VR Nuggets | 5 |
| FR19 | Movement Types | 100 |

Table 6.2: Functional Requirements Coverage in the First Prototype.

#### 6.6.3.2 Non-Functional Requirements Coverage

| ID | Name | Completeness (%) |
|---|---|---|
| NFR01 | Experience Equality | 0 |
| NFR02 | Accessibility | 30 |
| NFR03 | Usability | 30 |
| NFR04 | Performance | 100 |
| NFR05 | Compatibility | 100 |

Table 6.3: Non-Functional Requirements Coverage in the First Prototype.

#### 6.6.3.3 Technical Requirements Coverage

| ID | Name | Completeness (%) |
|---|---|---|
| TR01 | Standard File Format | 50 |
| TR02 | Asset Import | 50 |
| TR03 | Interoperability | 100 |
| TR04 | Hardware Compatibility | 100 |
| TR05 | VR SDK Compatibility | 100 |

Table 6.4: Technical Requirements Coverage in the First Prototype.

### 6.6.4 Informal User Feedback

Basic user testing was conducted with peers from the university to gather preliminary feedback. These tests were informal and exploratory in nature, but yielded several useful insights:

- Object manipulation was described as intuitive.
- Teleport and snap turn features were positively received for reducing motion sickness.
- The ability to avoid virtual keyboards was seen as a major usability advantage.
- The "grab move" feature was appreciated but noted as incomplete — users suggested the need for horizontal movement at elevated heights, not just vertical repositioning.
- Despite some intuitive features, the control bindings were not evident, and the suggestion was made to incorporate some pop-up hints to indicate what each button does.

- A version of *Virtual Choreographies* that can be used to structure the training procedure order and storage while also allowing for an automatic check on whether the correct procedures were conducted or not.

## 6.7 Discussion

This initial prototype demonstrates the feasibility of developing an accessible VR training authoring tool that can operate without requiring technical expertise. The JSON-based configuration system allows for modular and structured course creation, while the implemented movement and manipulation mechanics address several usability requirements identified in the literature.

However, several limitations were also observed:

- Lack of CAD model support limits applicability for real industrial contexts.
- Object import is constrained to pre-defined prefabs (at this moment).
- Communication and collaboration features are not yet implemented.
- Evolution of development tools (such as Unity) may impact future development as software updates are frequent and with major changes (e.g., change from Unity 5 to 6 or deprecated SteamVR).

These insights help define the roadmap for the next prototype iteration.

## 6.8 Changes to Requirements

The process of developing and evaluating the first prototype led to several modifications in the original set of requirements presented in Chapter 5. These include clarifications, refinements, deprecations, and the addition of new requirements that emerged from practical implementation and user feedback.

### 6.8.1 Changes to Functional Requirements

Table 6.5 presents the main functional requirement changes.

| ID | Name | Updated Description | Change Summary |
|---|---|---|---|
| FR13 | Desktop Authoring | The system should allow course creation on a desktop. | Marked as not feasible in the prototype due to architectural and time constraints. Deferred to future iteration. |
| FR20 | Controller Hints | The system should provide the user with hints on the controls. | **New requirement** introduced based on informal user feedback, improving usability and onboarding. |

Table 6.5: Changes to Functional Requirements After Prototype Evaluation.

### 6.8.2 Changes to Technical Requirements

Table 6.6 below outlines updates and refinements to the technical requirements, mainly related to platform compatibility and architectural decisions during development.

| ID | Name | Updated Description | Change Summary |
|---|---|---|---|
| TR05 (Old) | VR SDK Compatibility | The system should be developed using Unity3D with OpenXR or SteamVR for VR compatibility. | **Deprecated.** Superseded by updated requirement due to incompatibilities and plugin conflicts. |
| TR05 (New) | VR SDK Compatibility | The system should be developed using Unity3D 6.0 with OpenXR and the XR Interaction Toolkit 3.1.1 for VR compatibility. | **Updated** to reflect final development choices after removing SteamVR. |

Table 6.6: Changes to Technical Requirements After Prototype Evaluation.

## 6.9 New User Stories from Evaluation

Based on the limitations identified in Section 6, and the feedback collected during informal user testing, a new set of user stories was derived to guide the development of the next iteration of the prototype. These stories reflect the need for improved interaction, greater content flexibility, and some informative features.

The table below presents the new user stories that emerged from this process:

| ID | Name | Priority | Size | Description |
|---|---|---|---|---|
| US37 | Control Hints | High | S | As a User, I want to receive visual hints that map available actions to controller bindings to improve system usability. |
| US38 | Spawn Position Indicator | Medium | S | As a Trainer, I want a clear visual indicator of the starting position of trainees within the virtual environment. |
| US39 | Action Choreographies | High | S | As a User, I want training procedures to be stored as choreographies to simplify the understanding and analysis of user actions. |
| US40 | Horizontal Fly Mode | Medium | S | As a Trainer, I want to freely adjust my height and navigate the scene horizontally to better explore and validate the training setup from multiple perspectives. |

Table 6.7: New User Stories Derived from Prototype Evaluation.

## 6.10 Conclusion

The first prototype establishes a solid base for a VR training platform that supports immersive and non-immersive content creation. It enables the loading of training scenarios from a JSON configuration file, the manipulation of objects in the scene, and the customization of the training environment directly within VR.

The system empowers domain experts, particularly SMEs, to create high-fidelity (Al-Jundi and Tanbour 2022) and realistic training environments without relying on software developers. While current limitations prevent the use of external CAD models, future versions aim to overcome these restrictions and extend the platform's current functionalities, flexibility, and industrial applicability.

With a functional authoring pipeline and immersive environment interaction in place, the next steps involve expanding features, improving usability, and performing new evaluations on the next iteration.

# Chapter 7

# Second Prototype

## 7.1 Introduction

After the insights provided by the first prototype of this training platform, a new version could be developed. This chapter outlines this version and all that was learned from it.

The first prototype provided the foundation, and this second version continued to provide more functionalities, incorporate feedback obtained from previous tests, and also extend the support to new functional, technical, and usability requirements proposed in Section 6.8.

## 7.2 Improvements Over the First Prototype

The second prototype represents a substantial evolution of the initial system, incorporating lessons learned, addressing limitations, and implementing new features based on user feedback and unmet requirements. This section outlines the key areas in which the second prototype improves over the first.

### 7.2.1 Expanded Feature Coverage

The most significant improvement lies in the number of user stories and requirements that are now fully or partially implemented. While the first prototype focused on laying the groundwork, the second prototype brings many planned features into a functional state, including:

- **Virtual Choreographies:** A system to define and validate sequences of actions (Section 7.3.6).
- **Recording and Playback:** Initial implementation of action recording, enabling performance review and training demonstrations (Figure 7.14 and 7.15).
- **Object Interaction:** Complex objects can be disassembled and assembled with visual cues (Figure 7.10).
- **Documentation:** Access to training instruction documents (Figure 7.20).

### 7.2.2 Improved Usability and Accessibility

The first prototype's user interface was functional but limited. In this version:

- A **control hint system** was added to visually explain the controller bindings, improving onboarding and reducing frustration, as seen in Figure 7.2.
- The **radial menu** was restructured to reduce clutter and improve discoverability, particularly for new users (Figure 7.1).

These enhancements directly respond to feedback from informal testing in the first prototype.




Figure 7.1: Improved radial menu.

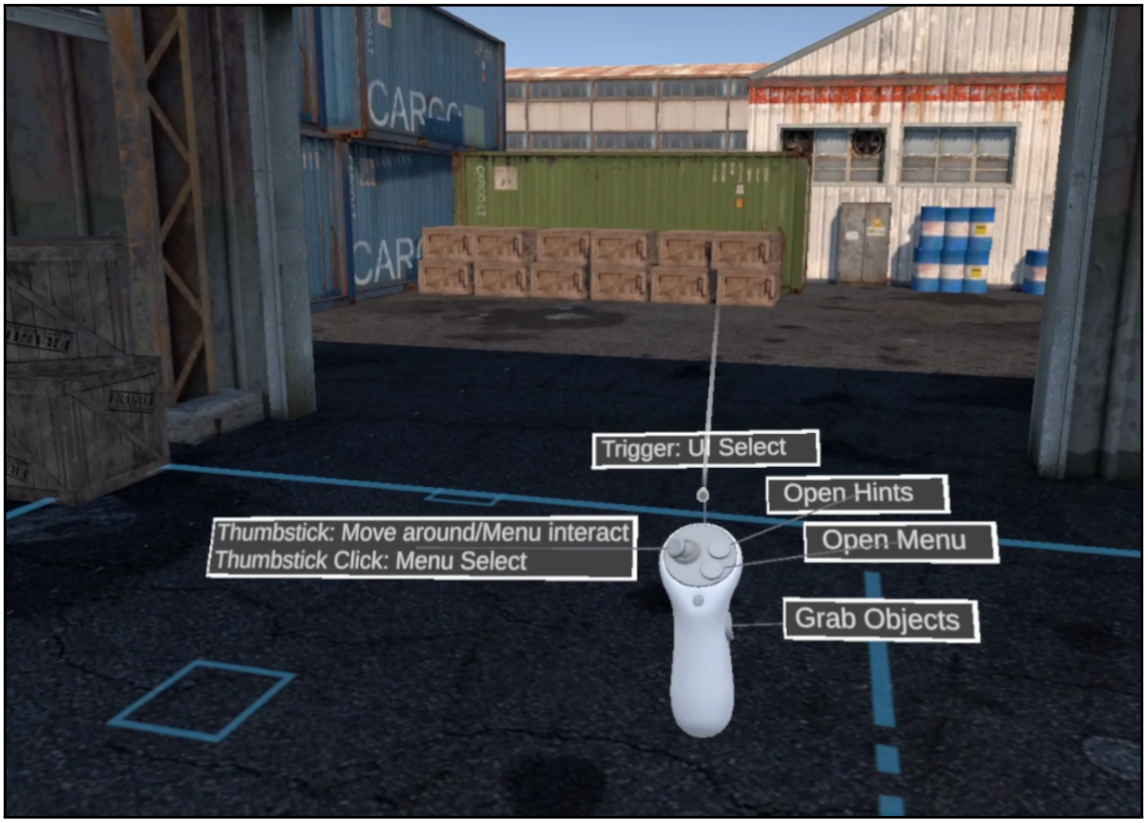



Figure 7.2: Hints for controller bindings.

### 7.2.3 Expanded Training Authoring

The authoring mode was significantly improved. Trainers now have access to multiple tools that allow them to customize both the training environment and procedures. The environment can be edited to make it look more realistic, and some complex objects, such as those derived from CAD data, can be incorporated as part of the training. Complex procedures can also be defined with multiple actions and steps as described in detail in Section 7.3.7.

### 7.2.4 Enhanced Movement System

Movement in VR is a critical factor for usability. The second prototype includes the following:

- Extended **grab-move functionality** with full 6DOF freedom, including horizontal repositioning, enabling better scene overview and inspection (Figure 7.9).
- Retained teleportation and snap-turn options for user comfort and accessibility (Figure 7.3).

These refinements support more fluid navigation for both the authoring and practice use cases.

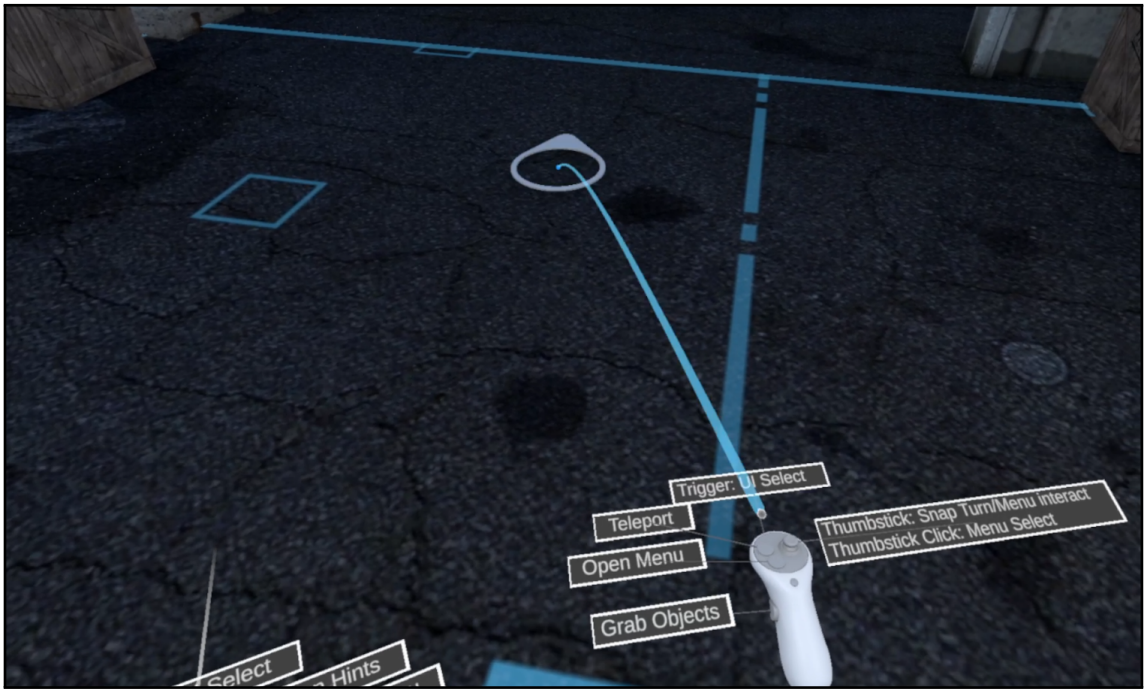



Figure 7.3: Teleportation feature.

### 7.2.5 Structured Configuration Format

The underlying JSON configuration system was redesigned with a formal schema that supports:

- Modular scenario definitions including environment metadata, and lists of props or complex objects (Section 7.3.1.1).
- Procedure and attempt recordings (Figure 7.6 and 7.7).
- Storage of metadata for video recordings (Figure 7.8).
- Documentation links and training mode settings.

This allows full training scenarios to be saved, shared, and reloaded across sessions — a key step toward real deployment and trainer autonomy.

### 7.2.6 Improved Code Architecture and Maintainability

Internally, the codebase was refactored for modularity and future expansion. Key changes include:

- Consolidation of object spawning and interaction logic.
- Reorganization of source code files.
- Separation of training modes into dedicated state handlers.
- Introduction of choreography and recording systems as independent modules, allowing clean future integration with analytics or evaluation logic.

### 7.2.7 Increased Requirement Fulfillment

In terms of traceability, this prototype closes a larger percentage of user stories (Table 7.1), functional (Table 7.2), non-functional (Table 7.3), and technical requirements (Table 7.4). Many previously unimplemented or partially implemented features now reach total or near-total completion, and several new requirements were identified and addressed through this iteration.

Overall, these improvements reflect a transition from a proof-of-concept to a more complete, modular, and user-oriented platform. The second prototype is not only more capable but also significantly more usable and maintainable, marking a critical step toward readiness for field deployment.

## 7.3 Implementation Details

This section describes the core technical improvements made in the second prototype, focusing on new or refined functionalities introduced to improve usability, extend authoring capabilities, and increase alignment with the defined requirements. Several features initially planned or requested through user feedback have now been fully or partially implemented, resulting in a more complete and user-friendly VR training platform.

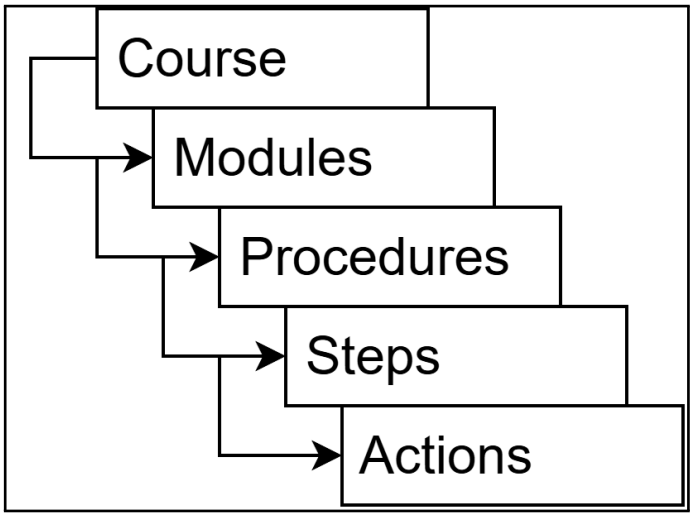



Figure 7.4: Course hierarchy.

### 7.3.1 Standard File Format

A major architectural improvement in the second prototype is the standardization of the environment configuration format, alongside other data types present in the application. The JSON schema has been updated and is divided into a few key components. This section outlines each.

This new format allows full scenes to be saved, shared, and reused across deployments. It also supports validation to ensure structural integrity before the scenario is loaded. The new schema improves future interoperability with external tools such as desktop editors.

#### 7.3.1.1 Configuration JSON

The configuration file is the file that is initially loaded when a training scenario is opened. It follows the course hierarchy (Figure 7.4), in the sense that each course has multiple modules, which have multiple procedures, and each procedure has an assigned configuration file. Figure 7.5 presents an example of a configuration file, which provides the following information to the application:

- Global environment metadata (e.g., environment, scene type).
- Course specifications (e.g., module, procedure).
- Objects in the scene, including type, position, rotation, scale, and interaction metadata.
- Mode configurations (authoring, practice, trainer test, or replay).

```
{
    "id": "AuthoringScene",
    "module": "Module_A",
    "procedure": "Procedure_X",
    "sceneType": "authoring",
    "environment": "Map_v2.prefab",
    "spawnPoint": {
        "position": [
            74.7918472290039,
            0.09059441089630127,
            -17.031217575073243
        ],
        "rotation": [
            0.0,
            2.8915603160858156,
            0.0
        ]
    },
    "attributes": {
        "labels": [
            "Label1",
            "Label2",
            "Label3"
        ]
    },
    "props": [
        {
            "name": "WoodenCableDrum_84b250",
            "file": "WoodenCableDrum.prefab",
            "position": [
                73.8009262084961,
                0.4762161076068878,
                -9.11671257019043
            ],
            "rotation": [
                359.97625732421877,
                359.9841003417969,
                0.010280211456120015
            ],
            "scale": [
                1.0118317604064942,
                1.0118317604064942,
                1.0118317604064942
            ]
        }
    ],
    "complexObjects": [
        {
            "name": "Engine01_4c8713",
            "file": "Engine01.prefab",
            "position": [
                83.72865295410156,
                0.9238014221191406,
                -15.892480850219727
            ],
            "rotation": [
                0.0,
                0.0,
                0.0
            ],
            "scale": [
                0.07299160212278366,
                0.07299160212278366,
                0.07299160212278366
            ]
        }
    ]
}
```


Figure 7.5: Example of an environment configuration file.

#### 7.3.1.2 Procedure JSON

While the configuration file's main purpose is to define and store the base setup of the environment for a specific training procedure, to actually store the procedure and the actions it requires, a

new data file was needed. This new file is, once more, in JSON format, and named after the module and procedure (e.g., "Module_A_Procedure_X.json") in which the steps and actions of a procedure are defined (hierarchy in Figure 7.4). For storing these actions and allowing for their match against trainee actions, a few details are tracked. These include a timestamp, a verb (detailed in Section 7.3.6), an object identification, and some coordinates or extensions if needed.

An example of this can be seen in Figure 7.6, where a simple, 1-step 1-action procedure is defined.


```
{
    "module": "Module_A",
    "procedure": "Procedure_X",
    "steps": [
        {
            "stepNumber": 1,
            "actions": [
                {
                    "timestamp": 266.0944519042969,
                    "verb": "drag",
                    "objectName": "Cylinder009",
                    "rootObject": "heavy-clutch_292090",
                    "prefabName": "heavy-clutch",
                    "extensions": {
                        "dropSite": "",
                        "position": {
                            "x": 0.0,
                            "y": 0.0,
                            "z": 0.0
                        }
                    }
                },
                {
                    "timestamp": 269.0992126464844,
                    "verb": "drop",
                    "objectName": "Cylinder009",
                    "rootObject": "heavy-clutch_292090",
                    "prefabName": "heavy-clutch",
                    "extensions": {
                        "dropSite": "DropZone_ea869d",
                        "position": {
                            "x": 84.238037109375,
                            "y": -0.23789334297180177,
                            "z": -4.221208572387695
                        }
                    }
                }
            ]
        }
    ]
}
```


Figure 7.6: Example of the choreography of a procedure.

#### 7.3.1.3 Procedure Attempt JSON

When trainees attempt a specific procedure, their actions are stored as *Virtual Choreographies* (Section 7.3.6) in JSON format. These are similar to the procedure JSON (Figure 7.6) but contain extra details for the runtime feedback provided to trainers, such as the number of correct or incorrect actions (Figure 7.18).


```
{
    "module": "Module_A",
    "procedure": "Procedure_X",
    "totalActions": 2,
    "correctActions": 1,
    "wrongActions": 1,
    "stepsCompleted": 0,
    "totalSteps": 3,
    "steps": [],
    "flatActions":[
        {
            "timestamp": 173.092738732,
            "verb": "drag",
            "objectName": "Cylinder009",
            "rootObject": "heavy-clutch_292090",
            "prefabName": "heavy-clutch",
            "extensions":{
                "dropSite": "",
                "position": {
                    "x": 0.0,
                    "y": 0.0,
                    "z": 0.0
                }
            }
        },
        {
            "timestamp": 174.923874382,
            "verb": "release",
            "objectName": "Cylinder009",
            "rootObject": "heavy-clutch_292090",
            "prefabName": "heavy-clutch",
            "extensions":{
                "dropSite": "N/A",
                "position": {
                    "x": 79.9872838231,
                    "y": 1.41231837201,
                    "z": -0.2928981276
                }
            }
        }
    ]
}
```


Figure 7.7: Example choreography of a procedure attempt.

#### 7.3.1.4 Recording JSON

The recording system (7.3.5) has a separate recording method from the procedure attempt recording. This was necessary since, for the attempts, only the actions were considered, but for a replay feature, more information about movement was needed. With this in mind, a proprietary recording system was created. It captures each frame that the recording is active, and stores details about the position and rotation of the head, controllers, and any object that has been grabbed, as seen in Figure 7.8.


```
{
    "frames": [
        {
            "time": 0.0148075046017766,
            "headPos": {
                "x": 74.17459869384766,
                "y": 1.8969835042953492,
                "z": -10.252062797546387
            },
            "leftPos": {
                "x": 73.997802734375,
                "y": 1.1998625993728638,
                "z": -9.88992977142334
            },
            "rightPos": {
                "x": 74.4475326538086,
                "y": 1.3180947303771973,
                "z": -10.138284683227539
            },
            "headRot": {
                "x": 0.34276002645492556,
                "y": 0.41883787512779238,
                "z": -0.14657758176326753,
                "w": 0.828013002872467
            },
            "leftRot": {
                "x": 0.21022191643714906,
                "y": 0.16693760454654694,
                "z": -0.15605027973651887,
                "w": 0.9505719542503357
            },
            "rightRot": {
                "x": 0.08601778000593186,
                "y": 0.38361862301826479,
                "z": 0.004862090572714806,
                "w": 0.9194640517234802
            }
        }
    ],
    "grabEvents": [
        {
            "startTime": 3.7584733963012697,
            "endTime": 7.43580436706543,
            "objectName": "Cylinder009",
            "prefabName": "heavy-clutch",
            "parentName": "heavy-clutch_292090",
            "objectPath": "Cylinder009",
            "motionFrames": [
                {
                    "time": 3.772402763366699,
                    "position": {
                        "x": 79.97225952148438,
                        "y": 1.3522756099700928,
                        "z": -0.37481117248535159
                    },
                    "rotation": {
                        "x": 0.0,
                        "y": 0.0,
                        "z": 0.0,
                        "w": 1.0
                    }
                }
            ]
        }
    ]
}
```


Figure 7.8: Partial recording of an attempt for replay.

### 7.3.2 Movement

The movement system from the first prototype was further refined to increase flexibility and address user feedback. The "grab move" feature now includes full horizontal and vertical motion, allowing users to float and reposition themselves freely within the scene. This is particularly useful for trainers when reviewing or modifying large or vertical environments (Figure 7.9).

To use this feature, users can hold the trigger and grab button on their controller, locking their hand in place and moving their camera around. The user will not be affected by gravity at this time, and even if in the air, the continuous movement and teleportation are still enabled.

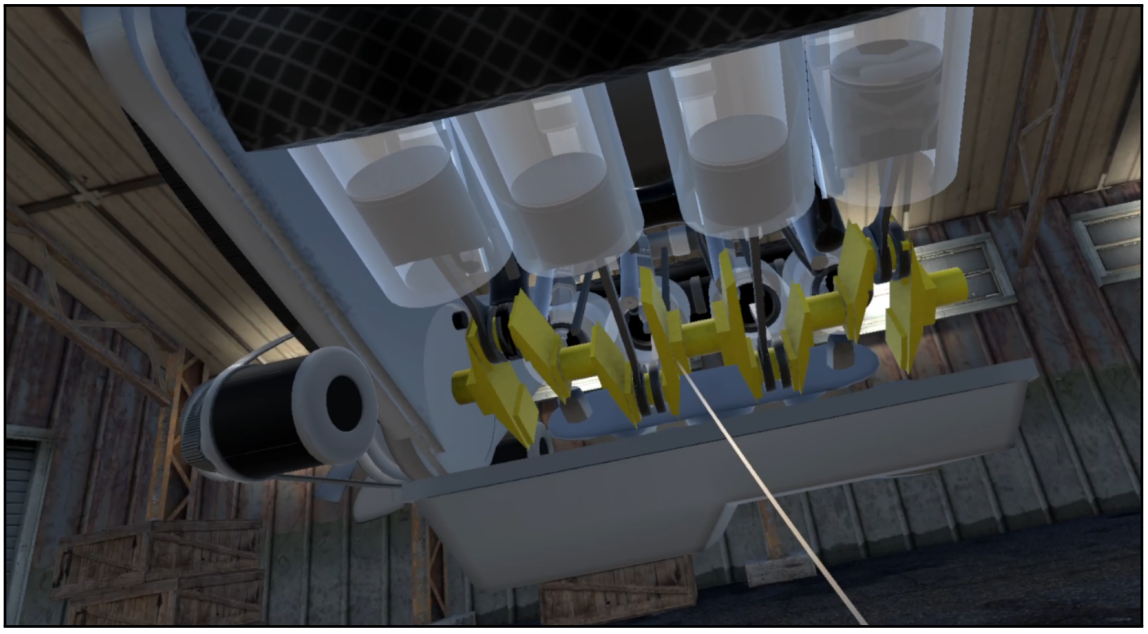


Figure 7.9: Adjustable POV.

The teleportation and snap-turn mechanics remain central, optimized to reduce motion sickness and disorientation. Additionally, transitions between different locomotion methods are now smoother, ensuring that users can seamlessly switch from teleport to free-move without needing to change modes or reconfigure settings.

### 7.3.3 New Authoring Features

The authoring environment was significantly expanded with new tools to give trainers finer control over object behavior, environment configuration, and procedure definition.

- **Object Interaction:** Objects defined as "interactables" can be disassembled part by part. This new version provides "ghost" visual guides when a part is close to its designated spot and includes automatic snapping when placing it in said spot (Figure 7.10).
- **Spawn Position:** The starting position of the training procedure can now be reassigned by trainers (Figure 7.11).

- **Environment Setup:** Trainers can add simple props, as well as fully configured interactable objects, to the scene (Figure 7.12).

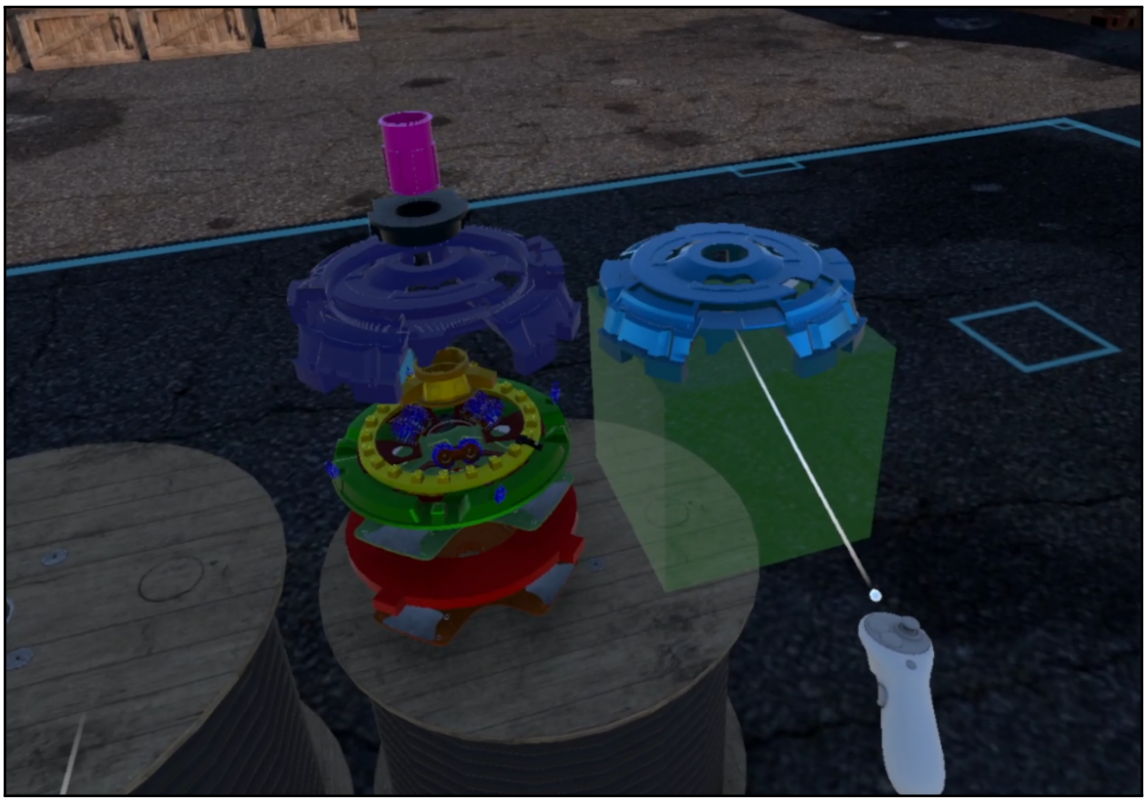


Figure 7.10: Object manipulation.



Figure 7.11: Reassigned starting position.

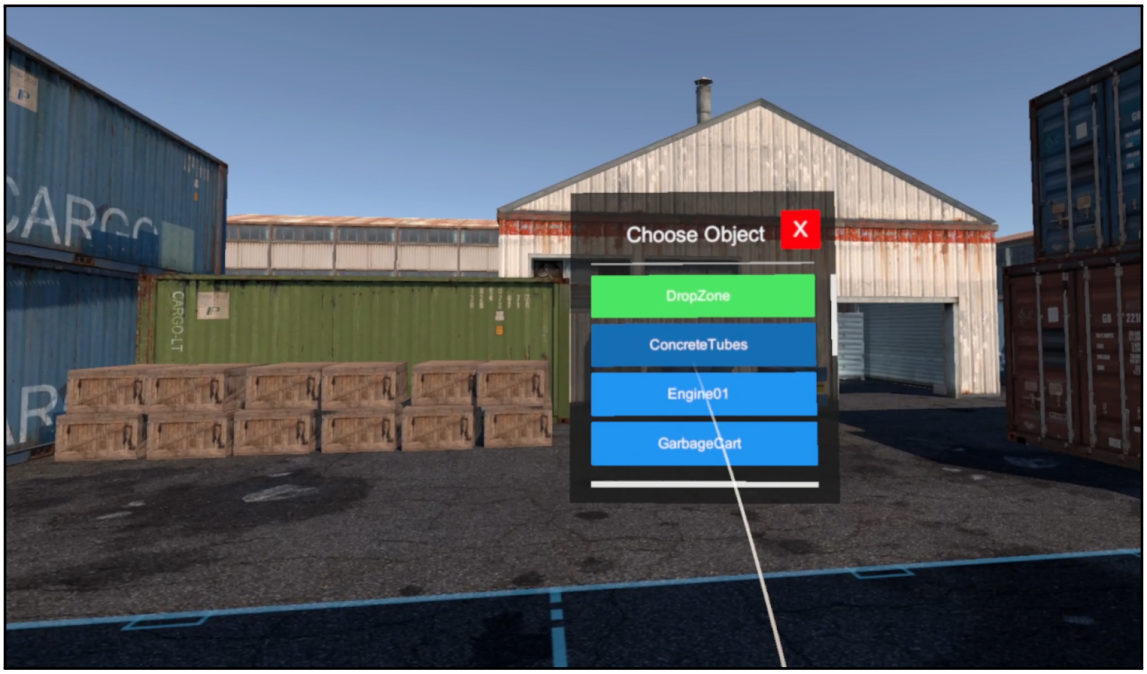



Figure 7.12: Adding a new complex object to the scene.

### 7.3.4 UI/UX Improvements

To enhance accessibility for non-technical users, multiple user experience improvements were implemented:

- **Control Hints:** When the user starts a session, visual cues are displayed to map the VR controller buttons to available actions (Figure 7.13). This was based on informal feedback from the first prototype and was inspired by the VRTraining platform (Fernando Cassola et al. 2021).
- **Simplified Radial Menu:** The radial menu was reorganized into sub-menus to avoid visual clutter and improve discoverability (Figure 7.1).
- **Action Feedback:** When the user performs certain actions such as updating the starting position of a procedure or initiating a recording, some visual aids appear to confirm the action has been successfully completed (Figure 7.14).
- **Menu Handling:** Using the menu no longer leaves users questioning whether their action was carried out or not. When users select an option from the menu that has no visible effects, the menu panel is hidden, adding direct feedback to the action.
- **Extra Information:** Users now have access to more information, such as summary reports (Figure 7.19) after a procedure attempt or real-time indicators of how many actions they did correctly or not (Figure 7.18).




Figure 7.13: Hints for controller bindings.

### 7.3.5 Recording System

A recording system was implemented to support the capture and replay of user actions. The system records a sequence of meaningful events, including head and controller position, as well as objects grabbed. These recordings can be applied in multiple scenarios.

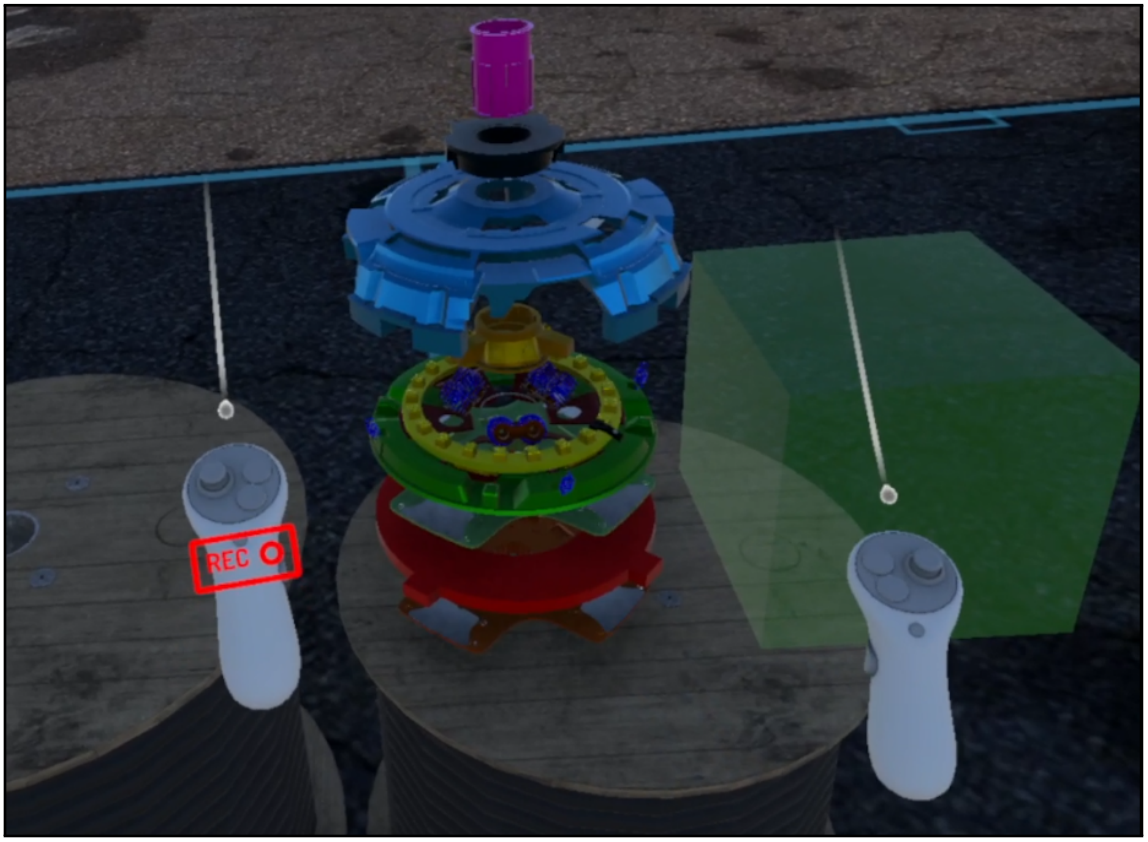



Figure 7.14: Recording a procedure attempt.

#### 7.3.5.1 Trainer Demonstrations

Trainers can create walkthroughs that trainees can later observe and replicate. This gives trainees a way to visually see how the procedure they want to replicate should be done (Figure 7.15).

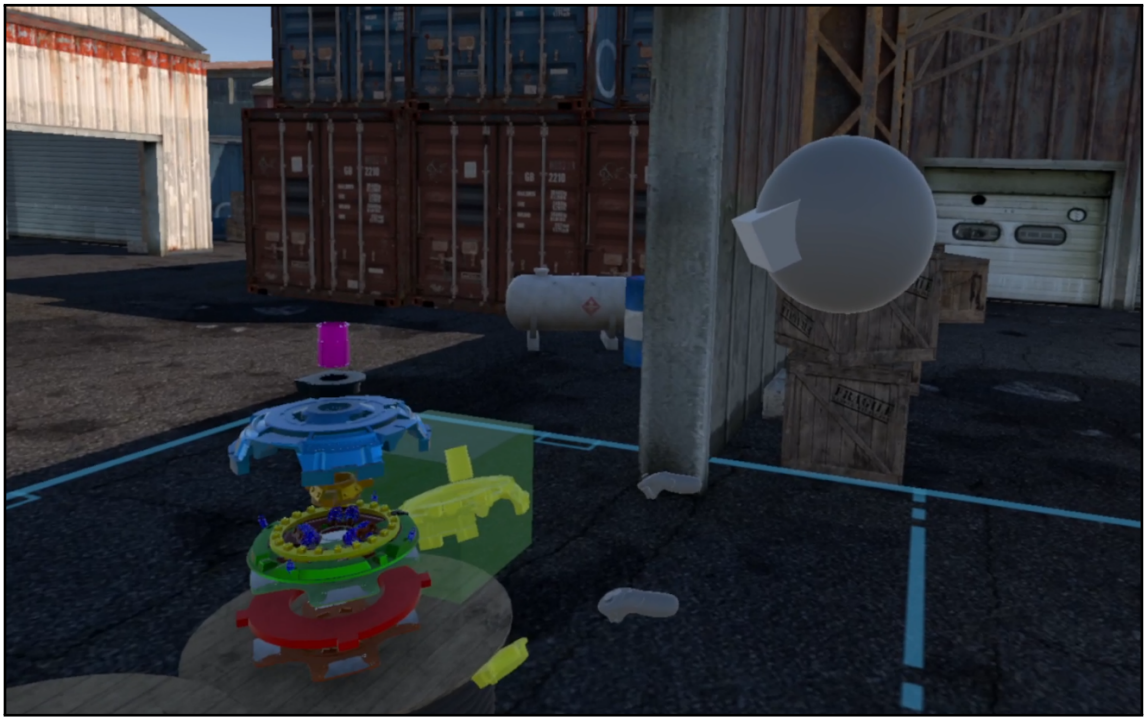


Figure 7.15: Replay of a procedure recording.

#### 7.3.5.2 Trainee Playback

Trainees can record their practice sessions so that they can then be reviewed for performance evaluation by trainers. These recordings are accessible to trainers in the Replay mode, where they can view all available recordings (including their own), carefully analyze them, and provide feedback to trainees (Figure 7.16).




Figure 7.16: Selecting a recording from the available ones.

As seen in Figure 7.16, when a trainer wants to select a specific recording, a UI dialog will appear with the list of available recordings. In this list, recordings are timestamped to identify them, and they also have one of the following prefixes: "Def_", "Rec_", and "Student_". "Def_" refers to the trainer demonstration of a procedure, this is the recording that will be played whenever a trainee selects the "Play" button in the "Video Guide" section of the menu. "Rec_" refers to a previous recording of a trainer that has been replaced by a newer version. Lastly, "Student_" identifies recordings generated by trainees in the practice mode, these are the ones trainers should review and analyze.

### 7.3.6 Virtual Choreographies

A key innovation in the second prototype is the integration of *Virtual Choreographies*. Within the prototype, they are used to allow trainers to define, sequence, and validate ordered interaction steps. Additionally, it allows for automatic attempt feedback.

*Virtual Choreographies* store user actions at a higher semantic level, allowing them to be easily reviewed and understood by trainers. Rather than storing actions as just coordinates and object names, actions are stored using names and verbs.

In the application, verbs indicate the action being performed, such as "release" for letting go of an object, "grab" for grabbing one, and "drop" for placing an object in a designated drop site.

Details about the action are also stored as "extensions". These can be the identification of a specific drop zone or the position where an object was released (Figure 7.7).

### 7.3.7 Procedure Definition

Using the *Virtual Choreographies* mentioned in section (7.3.6), trainers can define procedures (Figure 7.17), or in other words, sequences of required actions (e.g., grab object A, place it in drop zone B). These will then be stored in a structured JSON file, specifically linked to that procedure (Figure 7.6). These JSON files contain some fields used to identify the procedure, such as module, course, and procedure. They also store, in order, the steps to be completed. However, each step can include multiple actions, this is useful for actions that do not need to be followed in a specific order, such as removing a set of screws.

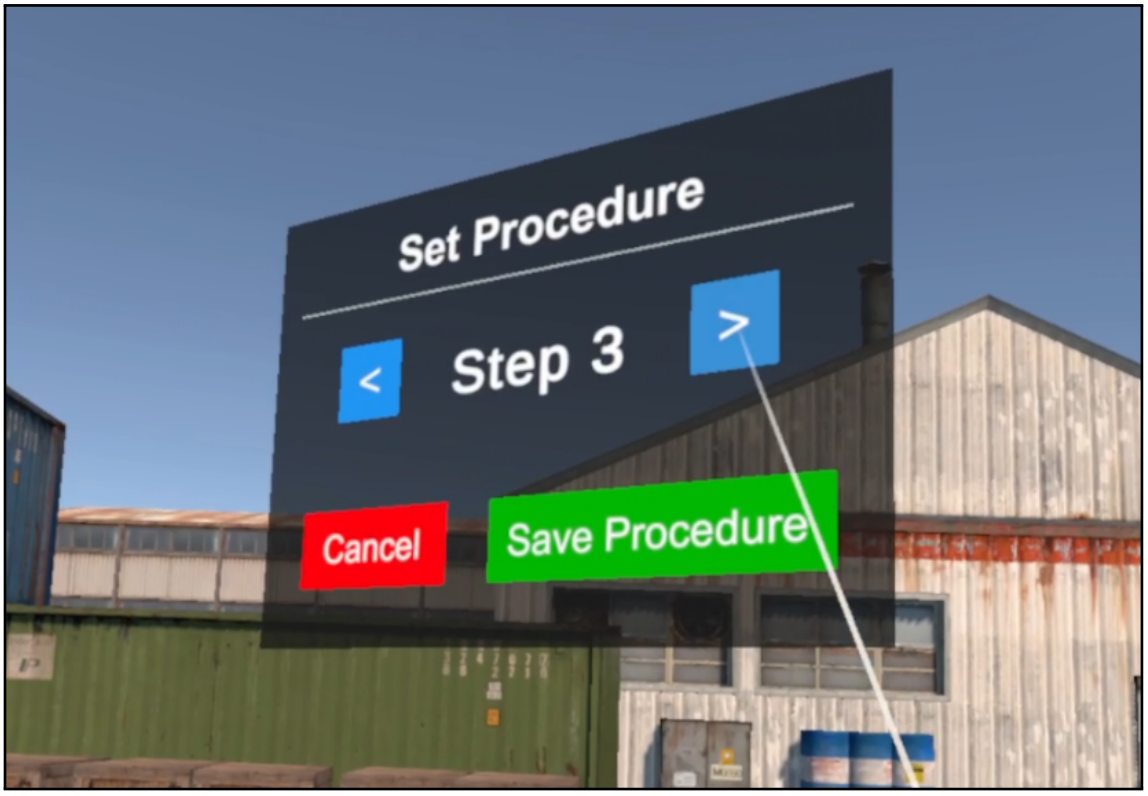



Figure 7.17: Procedure definition.

### 7.3.8 Procedure Attempt and Feedback

Trainees can then be guided through these procedures and receive real-time feedback on whether they are performing the correct steps in the correct order (Figure 7.18). This happens due to an algorithm running in the background that checks if the actions the user performed are the desired ones or not.




Figure 7.18: Real-time feedback on trainee actions.

Additionally, when a trainee completes an attempt, a UI panel opens up, showing a summary of the current attempt, including the number of correct actions, steps completed, and the expected number of correct actions (Figure 7.19).

This feature brings the platform closer to real industrial training requirements, where procedural correctness is critical.




Figure 7.19: Procedure attempt summary.

### 7.3.9 Documentation

The system now supports access to documentation mid-training. This allows trainees to view instructions or reference material during practice sessions. The documents should be provided and assigned by trainers to ensure materials are available when needed. In the current prototype, these files need to be manually uploaded as images, but it is expected for a future version to support direct PDF import and other formats.

Documentation is displayed in-world via floating panels that appear when a document is selected from a list (Figure 7.20). The list itself can be opened via an option in the radial menu. This reduces the need to exit VR or rely on external documentation.

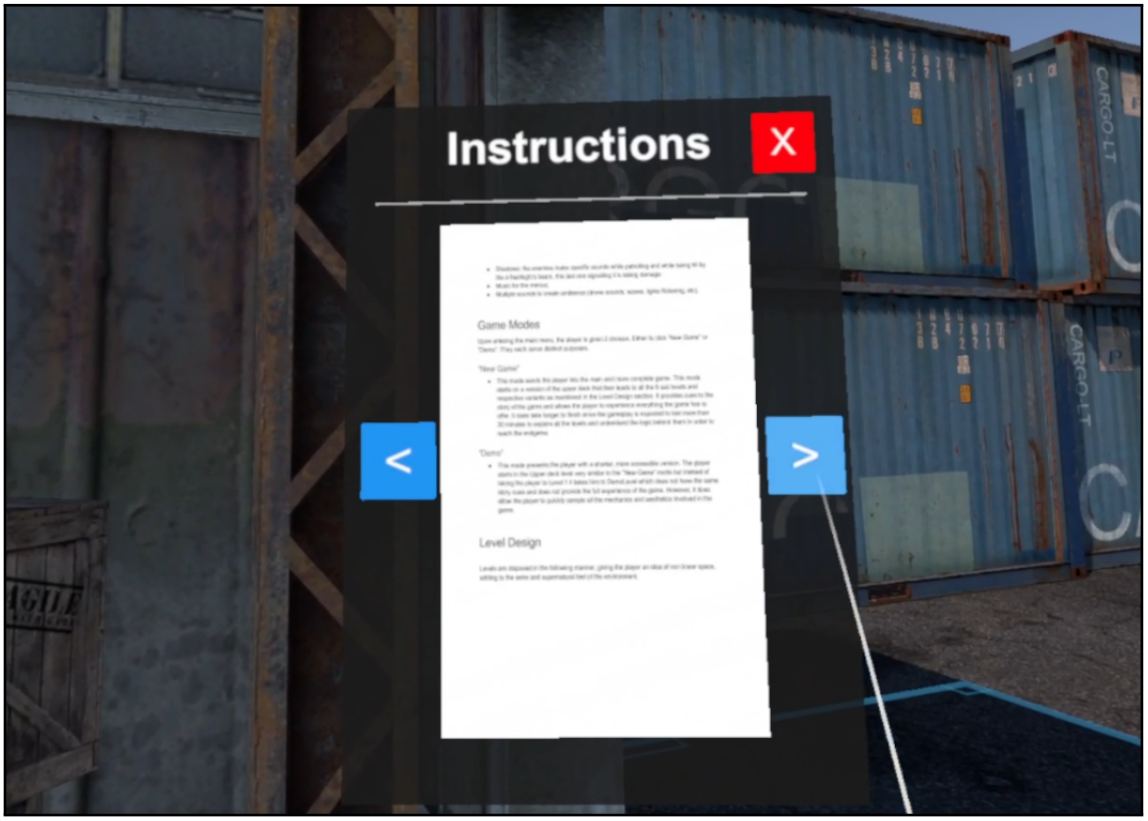



Figure 7.20: Access to documentation mid-training.

## 7.4 Demonstration

The state of the second prototype was also showcased in video format, more precisely, a video published on YouTube (Ferreira 2025b, Figure 7.21). This video shows all of the features implemented and serves as a demonstration of the potential of the system developed.

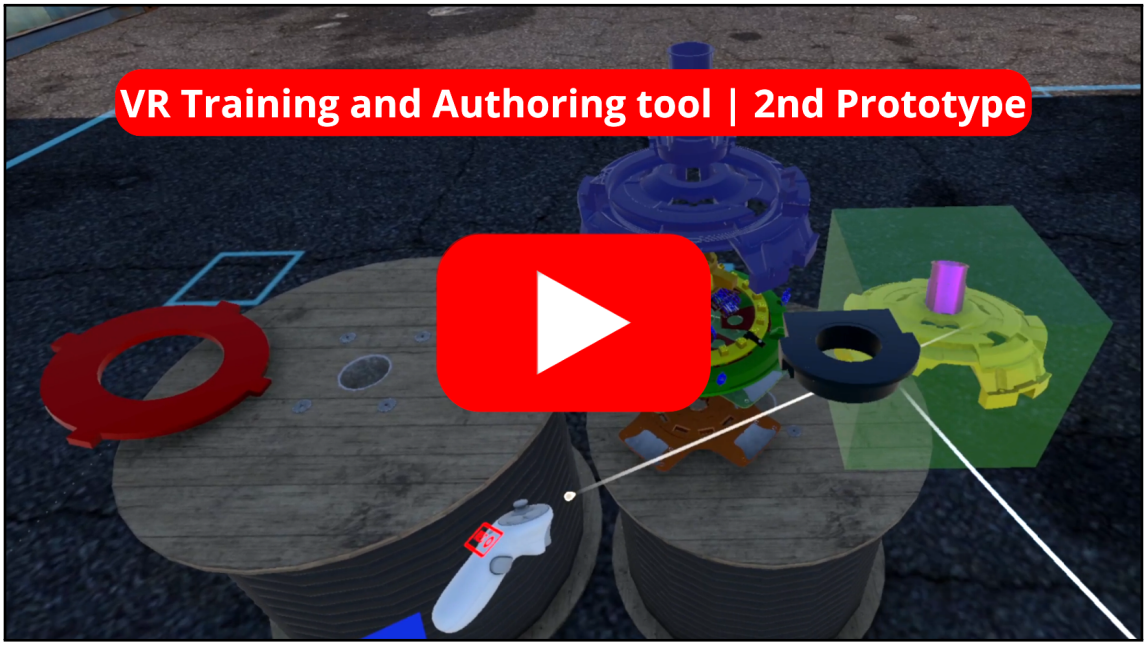



Figure 7.21: Thumbnail of the YouTube video demo for the second prototype.

## 7.5 Evaluation

### 7.5.1 Methodology

#### 7.5.1.1 User Story Validation

Similarly to the validation conducted on the first prototype, the user stories for this second system were once again validated. This process ensured each user story was reviewed and subjectively assessed as one of the following:

- Fully implemented;
- Partially implemented;
- Not implemented.

After manually inspecting every feature of the prototype, Table 7.1 was created. This allowed for a quick overview of the current state.

#### 7.5.1.2 User Tests

Unlike the previous prototype, which only had an informal user testing (Section 6.6.1.2), this second version had a more robust testing approach.

A supervised user test was conducted, as described in detail in Section 7.6. This approach validated the work developed so far and ensured important feedback was collected.

### 7.5.2 User Story Coverage

To assess the completeness of the prototype, the list of user stories defined in the previous Chapter 6 was revisited. Each story was reviewed to determine whether the current prototype implemented it, either fully or partially. These were then evaluated using a subjective estimation of implementation completeness.

The analysis showed that the prototype satisfies approximately **84%** of the defined user stories, which is a significant increase over the previous prototype, which only had 35%.

Section 7.7 outlines what is missing from the prototype, as well as the reasons why those features were left out.

| ID | Name | % Done | ID | Name | % Done |
|---|---|---|---|---|---|
| US01 | Authoring | 100 | US21 | Trainer VR Practice | 100 |
| US02 | Adjust Objects | 100 | US22 | Trainee VR Practice | 100 |
| US03 | Adjustable POV | 100 | US23 | Non-VR Text Inputs | 100 |
| US04 | Documentation | 100 | US24 | Asset Import | 100 |
| US05 | Documentation Selection | 50 | US25 | Asset Placement | 100 |
| US06 | Documentation Access | 100 | US26 | Collaborative Training | 0 |
| US07 | Record Trainer Actions | 100 | US27 | VR Communication | 0 |
| US08 | Record Trainer Voice | 0 | US28 | VR Nuggets | 100 |
| US09 | Record Trainee Actions | 100 | US29 | Interoperability | 100 |
| US10 | Record Trainee Voice | 0 | US30 | Movement Types | 100 |
| US11 | Storing Actions | 100 | US31 | Ease of Use | 100 |
| US12 | Trainer Action Replay | 100 | US32 | Matching Actions | 100 |
| US13 | Trainer Action View | 100 | US33 | Visual Display | 100 |
| US14 | Content Import | 100 | US34 | Resource Sharing | 100 |
| US15 | Content Export | 100 | US35 | Action Ordering | 100 |
| US16 | Standard Course Format | 100 | US36 | Action Ordering Specification | 100 |
| US17 | Pre-made Examples | 100 | US37 | Feedback Mechanism | 100 |
| US18 | Placeholders | 100 | US38 | Session Control | 100 |
| US19 | Desktop Authoring | 100 | US39 | Session History | 100 |
| US20 | VR Authoring | 100 | US40 | Scenario Switching | 100 |

Table 7.1: User Stories Coverage in Second Prototype.

### 7.5.3 Requirements Coverage

To complement the user story assessment, the functional, non-functional, and technical requirements updated in the previous Chapter 6 were also revisited and analyzed based on their implementation status in the second prototype. For each requirement, the subjective completeness percentage was reviewed and updated to reflect its current state. Tables 7.2, 7.3, and 7.4 summarize this review.

#### 7.5.3.1 Functional Requirements Coverage

| ID | Name | % Done |
|---|---|---|
| FR01 | Authoring | 100 |
| FR02 | Object Handling | 100 |
| FR03 | Adjustable POV | 100 |
| FR04 | Documentation | 100 |
| FR05 | Action Recording | 90 |
| FR06 | Action Storage | 100 |
| FR07 | Action Replay | 100 |
| FR08 | Import/Export | 100 |
| FR09 | Pre-made Examples | 100 |
| FR10 | Asset Placeholders | 100 |
| FR11 | Authoring Tools | 100 |
| VR12 | VR and Non-VR Mix | 100 |
| FR13 | Desktop Authoring | 0 |
| VR14 | VR Authoring Refinement | 100 |
| FR15 | VR Practice | 100 |
| FR16 | Desktop Text Input | 100 |
| FR17 | Communication | 0 |
| FR18 | VR Nuggets | 100 |
| FR19 | Movement Types | 100 |
| FR20 | Controller Hints | 100 |

Table 7.2: Functional Requirements Coverage in Second Prototype.

#### 7.5.3.2 Non-Functional Requirements Coverage

| ID | Name | % Done |
|---|---|---|
| NFR01 | Experience Equality | 100 |
| NFR02 | Accessibility | 100 |
| NFR03 | Usability | 100 |
| NFR04 | Performance | 100 |
| NFR05 | Compatibility | 100 |

Table 7.3: Non-Functional Requirements Coverage in Second Prototype.

#### 7.5.3.3 Technical Requirements Coverage

| ID | Name | % Done |
|---|---|---|
| TR01 | Standard File Format | 100 |
| TR02 | Asset Import | 50 |
| TR03 | Interoperability | 100 |
| TR04 | Hardware Compatibility | 100 |
| TR05 | VR SDK Compatibility | 100 |

Table 7.4: Technical Requirements Coverage in Second Prototype.

## 7.6 Usability Case Study

To evaluate the usability of the VR training and authoring platform, a user study involving 15 participants was conducted. Participants were asked to perform authoring and procedure practice tasks that would replicate the intended usage of the application. The test aimed at placing participants in both trainer and trainee roles and seeing how they felt about each one.

### 7.6.1 Participants

The case study consisted of 15 participants, most of them faculty members and students (12 of the 15), aged between 18 and 65 years. Their backgrounds were quite varied, and they possessed no prior technical knowledge of industrial procedures. This was seen as an advantage since the platform should be accessible to everyone, regardless of their skill level. Even though 80% of participants had some type of previous contact with VR headsets, the other 20% shared similar feedback on the tasks, indicating this lack of experience was not an issue.

### 7.6.2 Method

The study conducted was a supervised practical test, where users interacted with the application to perform a series of tasks (task script in Appendix A.2), with a duration between 10 and 20 minutes, depending on the level of participant engagement and exploration. Their attempts were closely monitored, and tips were provided when needed. However, when this happened, a log entry was added to mention what made them require a hint.

After the practical test, participants were asked to fill out a form with 3 sections: 1) basic questions about their demographic and VR experience (e.g., age and prior VR contact); 2) a series of questions with Likert-scale ratings (1–5); 3) a few open-ended questions to provide feedback (form and answers in Appendix A.4 and A.5, respectively).

### 7.6.3 Tasks

When starting the test, participants were asked to play around with the movement mechanics and basic object handling, in order to understand the basis of the platform. Then, they were asked to take on the role of a trainer and configure a training environment by adding a few props and objects to interact with. They would also explore the feature to define a new procedure. Afterwards, they would take on the role of a novice trainee attempting a simple procedure for the first time. For this, they would have to access a document with instructions (Appendix A.3) and use the video replay to see how the procedure had to be done. With this information, they were asked to attempt the procedure without any mistakes.

### 7.6.4 Results

#### 7.6.4.1 Ease of Use

Most users (12) rated task difficulty between 4 and 5 (5 = Very Easy), indicating strong usability across the system's main features. Tasks such as grabbing/moving objects and using the menu were consistently described as intuitive despite some subjective suggestions for improvement.

#### 7.6.4.2 Challenges

Despite the positive feedback, some participants (6) indicated that the defined control bindings for rotating and scaling objects were not intuitive and conflicted with the camera's snap turn functionality. The menu bindings were also seen as complicated by 5 users. It was also observed that the platform involved a slight learning curve, especially for users unfamiliar with video game controllers.

A lack of visual confirmation for specific actions was also noted by 4 participants, where participants could not identify whether a particular action had been completed or even in which mode they were currently in.

As is common with VR platforms, motion sickness remains an issue for a minority of users (3). Also, the feedback provided suggests some features, such as a slow speed for the "grab move" feature or the teleportation mode, helped reduce motion sickness.

### 7.6.5 Case Study Conclusion

All participants stated they could use the platform to create training content with minimal guidance and practice procedures without consequences. Responses highlighted the system's accessibility and potential, especially when minor usability issues are addressed.

## 7.7 Features Not Implemented

Despite significant progress in the second prototype, a few features outlined in the requirements remain unimplemented. These were de-prioritized due to technical complexity, time constraints, or to allow better focus on the most impactful elements of the user experience. This section summarizes the key features that were not included in this iteration.

### 7.7.1 Collaboration

The system was originally intended to support multi-user scenarios where trainers and trainees could collaborate or observe training sessions in real-time. However, implementing real-time networking and multi-user synchronization across different devices and network conditions was deemed out of scope for the current iteration.

Real-time collaboration remains an interesting option to explore in a future version.

### 7.7.2 Voice Integration

Although mentioned in both the requirements and feedback, no voice chat or voice recording functionality was implemented. The intention was to allow trainers to narrate procedures and offer verbal instructions while also capturing trainee verbal feedback or narration during practice.

This feature was delayed due to the need for audio device compatibility, voice data streaming/storage, and potentially privacy considerations. Moreover, voice systems require fine-tuning to ensure clarity and avoid feedback in noisy environments.

### 7.7.3 Complex Document Loading

While the system supports simple documentation panels and embedded instructions through the loading of sequences of images, it does not yet support loading complex or interactive documentation such as PDFs, CAD-associated manuals, or instructional videos.

Rendering these types of documents inside VR requires additional parsing/rendering pipelines (e.g., for PDF or HTML), UI presentation layers, and interaction mechanisms for scrolling, zooming, or playback. These were considered secondary to core training and authoring workflows and were therefore postponed.

### 7.7.4 Desktop Authoring

A desktop-based authoring interface was initially proposed (FR13 in Table 5.3), allowing trainers to prepare courses without entering VR. However, implementing such a system would require a full GUI-based editor, validation system, and synchronization pipeline to ensure parity with VR-authored scenarios.

Due to the complexity and required resources, desktop authoring fell outside the scope of this thesis and was deferred. The configuration file can still be manually edited to tweak training setups, but no visual desktop editor has been implemented yet.

## 7.8 Discussion

The second prototype significantly improves upon the initial proof of concept by expanding core functionalities, refining interaction models, and incorporating user feedback into a more mature and usable system. Many foundational requirements are now addressed, and the platform is closer to being deployable in real-world training contexts.

**What Was Achieved:**

- Full authoring pipeline within VR, including object placement, task sequencing, and environment configuration.
- A robust and extensible configuration file system supporting shareable and modular scenario creation.
- Usability enhancements such as control hints and simplified menus, directly targeting the needs of non-technical users.
- Introduction of *Virtual Choreographies* to structure and validate training procedures.
- Access to documentation mid-training.
- Proprietary recording and replay system allowing for playback of attempts.

**What Remains Challenging:**

- Features related to social interaction (collaboration, voice) are still missing and will require architectural extensions and external dependencies.
- The lack of desktop authoring limits accessibility for users who prefer to set up training scenarios outside of VR.

- Documentation access and model import remain functional but minimal. There is room to expand support for external files, formats, and in-VR browsing.

**Design Trade-Offs:** The decision to prioritize in-VR authoring and usability over more technical or networked features was deliberate. It allowed for fast iteration, high-impact improvements, and a clearer demonstration of the system's value to domain experts.

**Future Implications:** The prototype's architecture and user feedback suggest that the system is ready to be tested in more structured pilot studies, ideally within industrial or training center environments. The ability to author and deliver immersive training content without programming experience provides strong potential for adoption.

While there are still limitations, the second prototype achieves a balance between technical feasibility and real user needs, setting a solid foundation for continued development or handoff to a production-ready team.

## 7.9 Communication

To share the findings and contributions of this project with the broader academic and professional community, a scientific paper was written based on the state of the second prototype and the work detailed in this thesis (Appendix A.1). This paper focused on the technical innovations, usability improvements, and practical implications of the platform, particularly the in-VR authoring system, *Virtual Choreographies*, and the action recording and feedback mechanisms.

The paper was submitted to the IEEE International Symposium on Emerging Metaverse (ISEMV), a peer-reviewed conference in the field of the Metaverse and the connection between the physical and digital world. It serves both as a summary of the research and as a means of validating the approach within the research community.

By disseminating this work through formal academic channels, the goal is to encourage further development, foster collaboration, and inspire similar initiatives to make immersive training platforms more accessible, maintainable, and effective in real-world settings.

## 7.10 Conclusion

This prototype presents a VR-based training platform that allows non-expert users to author, execute, and evaluate immersive training scenarios. The system supports complete setup of the virtual reality environment, procedure definition, recording and replay of user actions, and structured performance evaluation using *Virtual Choreographies*.

Designed with accessibility in mind, the platform uses intuitive interfaces, such as radial menus, control hints, and configuration files to reduce the learning curve for domain experts. A user testing session confirmed the usability and functionality of the platform, while also identifying areas for improvement.

The integration of procedure recording, replay, automated validation, and the ability to use the platform to create and update training scenarios without professional developer skills distinguishes

this work from many VR training solutions that require manual supervision or development expertise. The system provides a foundation for future extensions, including collaborative training, voice interaction, and desktop-based authoring, with the long-term goal of supporting scalable, customizable training across domains.

### 7.10.1 Limitations

While the proposed platform demonstrates strong potential for accessible VR training authoring, several limitations remain:

- **No Collaborative Functionality:** The system is currently designed for single-user sessions. Multi-user collaboration — including real-time trainer-trainee interaction — is not yet supported, but could be an effective addition to improve the quality of training.
- **Limited Input Modalities:** Voice commands and voice recordings are not implemented. This limits the realism of certain training tasks, especially those involving verbal procedures or communication.
- **Fixed Asset Library:** All available props and interactable objects must be pre-loaded into the prototype system. A complete version should support runtime import of external CAD models or user-provided assets.
- **VR-Only Authoring:** Trainers must use a VR headset to configure scenarios. Although JSON files can be edited manually, there is currently no desktop authoring interface for trainers who prefer non-immersive environments.
- **Simplified Choreography Checking:** The choreography validation tool is order-sensitive but does not yet handle complex logic such as conditional branches, timing constraints, or parallel tasks.
- **Simple documentation system:** Documents are currently limited to static images, and there is no native support for complex or interactive formats like PDFs or videos.
- **Motion Sickness:** Despite the efforts to combat motion sickness, for some users (3), even short VR exposure can cause some discomfort.
- **Tutorial:** A few users (3) felt the need for an interactive onboarding/tutorial system to soften the platform's learning curve (Horst et al. 2020).
- **Unintuitive Object Manipulation:** Rotation and resizing controls were cited as unintuitive, limiting precise scene configuration and causing user frustration.

These limitations are mostly technical rather than conceptual and can be addressed in future iterations.

### 7.10.2 Future Work

Considering the current prototype and the research conducted, some steps could be taken to improve the application's functionality, usability, and training effectiveness.

- **Desktop Authoring Interface:** A companion desktop application could be developed to allow trainers to configure environments and procedures without entering VR. This would reduce the exhaustion involved with VR usage and bypass typical VR annoyances, such as the use of VR keyboards, since text inputs could be added in desktop mode and accessed later in VR.
- **Collaboration and Networking:** Support for multi-user sessions will enable trainers to supervise trainees remotely or conduct joint sessions.
- **Voice Integration:** Adding support for voice guidance, narration, and voice-based evaluation could enhance immersion and task realism (Fernando Cassola et al. 2022).
- **Asset Import Pipeline:** Runtime support for importing CAD or common 3D file formats will make the system applicable in real industrial settings.
- **Documentation Import:** Runtime support for multiple formats of documentation could improve the system's versatility.
- **Advanced Choreography Logic:** Future versions could support conditional flows, optional steps, and error recovery mechanisms in action sequences.
- **Formal Evaluation:** A larger-scale user study with professional trainers and real trainees should be conducted to evaluate learning effectiveness and long-term usability (Horst et al. 2022).
- **Tutorial:** The platform could benefit from an animated tutorial to facilitate the experience for new users (Horst et al. 2020).
- **Procedure Descriptions:** Including textual descriptions of procedures within the VR scene could help users understand what they are actively doing, leading to a more effective learning process.
- **Virtual Choreography to PDF:** The current choreography system could be used to convert attempt reports into detailed PDF files with clear descriptions of what was done, enabling trainers to simply read a report of their student's performance.
- **Enhanced Object Manipulation Tools:** Adding visual rotation guides, snapping systems, or more intuitive scaling methods would reduce setup errors and improve precision.

Research shows (Beck and Morgado 2025) that the phenomenon of Immersion arises not only by users being visually enveloped by virtual environments, but also in combination with the meaning of the events and goals (the narrative dimension), and by the plausibility of the range of experiences available and the range of interaction options (the agency dimension). We aim to expand the authoring tool to encompass these aspects, linking it to learning management systems and overall learning planning tools.

# Chapter 8

# Conclusions

The problem addressed in this work was the complexity and cost of developing immersive industrial training experiences, especially when it came to content creation and procedural validation. While VR has proven benefits for skill acquisition and knowledge retention, its adoption in training contexts is still hindered by the lack of user-friendly authoring tools with the ability to keep training scenarios up-to-date.

The primary objective was to answer three research questions regarding the design and development of a VR-based training and authoring platform. Secondly, this acquired knowledge was put to use by creating a VR-based training platform that enabled trainers to design, execute, and evaluate training procedures without programming expertise. Specifically, the system needed to support configurable environments, intuitive authoring tools, action recording and replay, and feedback mechanisms for trainees.

To achieve this, the research went through a literature review and a systematic review to attempt to answer the research questions, followed by a design, science, and research approach to develop a working prototype (Chapter 4). A first prototype served as a proof of concept and provided information for the design of a second, more complete version. This second prototype implemented a modular configuration schema, in-VR authoring tools, integrated *Virtual Choreographies* for action tracking, documentation features, and a recording and playback system. A structured user study with 15 participants was also conducted to evaluate the system's usability.

In conclusion, this work successfully demonstrates that immersive authoring and training platforms can empower non-technical users to define, deliver, and evaluate VR-based learning experiences, significantly reducing the overhead typically associated with content creation and evaluation.

## 8.1 Main Findings

The key outcomes of this thesis include:

- A fully functional VR training platform that supports scenario creation, execution, and replay.

- A list of features that a VR training system should incorporate to be effective and adaptable (Section 5.2).
- Integration of *Virtual Choreographies* — a semantic action logging and validation framework — enabling real-time and post-session feedback, as well as an easier understanding of user actions.
- Implementation of a standard, extensible JSON configuration format that separates concerns (e.g., environment, procedures, attempts, recordings).
- A custom recording and playback system that allows trainers to create demonstrations and review trainee sessions.
- Positive usability feedback from a supervised case study involving 15 participants with diverse backgrounds.

These results show that VR authoring and training tools can be made accessible to non-experts while still offering powerful capabilities for structured procedural training.

## 8.2 Limitations

While the second prototype made considerable progress, a few limitations remain:

- **No real-time collaboration:** Multi-user interactions (e.g., trainer and trainee in the same scene) were not implemented.
- **Lack of research:** Despite the multiple articles published on the matter, there is still a lack of research into VR authoring platforms.
- **Lack of standardization:** The lack of a standard for evaluating the training effectiveness of a VR training platform complicates the comparison of research.
- **Voice integration is absent:** Neither voice-over narration nor audio feedback was included due to technical, time, and privacy considerations.
- **Document integration is limited:** Documentation is currently limited to image-based formats. PDF and video support are not yet available.
- **No desktop authoring:** Trainers must use VR to author scenarios. A separate desktop interface for scenario creation was not developed.
- **Manual file handling:** While the JSON format is flexible, editing and managing files still requires some technical understanding or support.
- **User Feedback:** The prototype developed lacked user feedback in the form of UI and UX features to improve the experience.

- **Pre-configured assets:** The prototype relies on pre-added assets and does not have the ability to import external models (CAD data) and files in multiple formats.

## 8.3 Future Work

Future work on this subject can address the above limitations and extend the capabilities of the system.

- **Desktop Authoring Interface:** A companion desktop application could be developed to allow trainers to configure environments and procedures without entering VR. This would reduce the exhaustion involved with VR usage and bypass typical VR annoyances, such as the use of VR keyboards, since text inputs could be added in desktop mode and accessed later in VR.
- **Collaboration and Networking:** Support for multi-user sessions will enable trainers to supervise trainees remotely or conduct joint sessions.
- **Voice Integration:** Adding support for voice guidance, narration, and voice-based evaluation could enhance immersion and task realism (Fernando Cassola et al. 2022).
- **Asset Import Pipeline:** Runtime support for importing CAD or common 3D file formats will make the system applicable in real industrial settings.
- **Documentation Import:** Runtime support for multiple formats of documentation could improve the system's versatility.
- **Advanced Choreography Logic:** Future versions could support conditional flows, optional steps, and error recovery mechanisms in action sequences.
- **Formal Evaluation:** A larger-scale user study with professional trainers and real trainees should be conducted to evaluate learning effectiveness and long-term usability (Horst et al. 2022).
- **Tutorial:** The platform could benefit from an animated tutorial to facilitate the experience for new users (Horst et al. 2020).
- **Procedure Descriptions:** Including textual descriptions of procedures within the VR scene could help users understand what they are actively doing, leading to a more effective learning process.
- **Virtual Choreography to PDF:** The current choreography system could be used to convert attempt reports into detailed PDF files with clear descriptions of what was done, enabling trainers to simply read a report of their student's performance.
- **Enhanced Object Manipulation Tools:** Adding visual rotation guides, snapping systems, or more intuitive scaling methods would reduce setup errors and improve precision.

- **Analytics and dashboards:** Developing visual tools to review and compare performance metrics across multiple trainees or sessions.
- **Integration with external LMS systems:** Enabling the system to report scores and progress to a central learning management platform.

## 8.4 Closing Thoughts

The work presented in this thesis bridges the gap between immersive training technology and usability for non-technical stakeholders. By enabling trainers to create structured, interactive procedures with minimal technical intervention, it lays the groundwork for broader adoption of VR training platforms in real-world environments. This shift has the potential to enhance the quality of training across multiple sectors, reduce industrial costs, and improve safety during procedures that would otherwise be dangerous or impractical to simulate.

At its core, this research argues for a model in which immersive learning technologies empower rather than replace professional trainers. Many modern systems attempt to automate expertise, often sidelining the human element in favor of efficiency. This thesis takes a different path. Through the development and evaluation of VR Training, it demonstrates that involving subject matter experts (SMEs) in the authoring process leads to more meaningful, realistic, and effective training. The proposed tool allows SMEs to design and implement immersive learning experiences without requiring programming knowledge or large development budgets, ensuring that technical barriers do not stand in the way of educational innovation.

The developed prototype further validates this approach, offering a proof-of-concept that illustrates both the feasibility and the potential of such systems. While not exhaustive in scope, it highlights important directions for future research and development. In particular, the opportunity to improve communication and feedback between trainers and trainees within the virtual environment remains significant. Immersive spaces offer unique affordances — from real-time interaction to spatial memory support — that can elevate learning far beyond traditional training approaches.

This thesis ultimately contributes to simplifying and expanding the use of VR training, not only for learners but also for those tasked with delivering education and certification. It reaffirms the value of human expertise in digital contexts and emphasizes the importance of designing tools that are inclusive, adaptable, and grounded in real pedagogical needs.

On a personal level, this journey has reinforced my commitment to developing human-centered technology and deepened my appreciation for the role of immersive environments in transforming how we teach, learn, and certify skills. It is my hope that the ideas and tools presented here inspire further exploration and help shape a future where immersive education is more accessible, impactful, and empowering — for trainers and trainees alike.

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# Appendix A

# Appendix

## A.1 Paper submitted to IEEE International Symposium on Emerging Metaverse 2025

# VR Training and Authoring Tool for Industrial Training using Virtual Choreographies

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***Abstract*—Virtual Reality (VR) is a powerful tool for industrial training due to its capacity to simulate realistic, risk-free environments. However, creating VR training scenarios often requires significant technical expertise and large investments, limiting the technology's adoption. This paper presents a VR training platform that empowers trainers to author, test, and deliver immersive training procedures directly within a VR environment without writing code. It also gives trainees a place to practice and learn without consequences. A key feature is the integration of *Virtual Choreographies*, enabling trainers to define ordered procedures, record trainee attempts, more easily understand their actions, and automatically assess performance. A user study was conducted to evaluate usability, workflow clarity, and feature effectiveness. Results indicate strong usability and comprehension for non-expert users, and confirm the potential of *Virtual Choreographies* to guide and evaluate procedural training. The platform represents a step toward creating accessible, customizable VR training for industrial and educational settings.**

***Index Terms*—Virtual Reality, Virtual Choreographies, Authoring, Training, Immersive, Education, Industrial**

## I. Introduction

Virtual Reality (VR) training environments offer a powerful alternative to traditional learning, allowing students to participate in realistic and interactive simulations without the risks or constraints of physical spaces. In industries where safety, precision, or repetition are critical, such as manufacturing, maintenance, and healthcare, VR has the potential to improve learning outcomes and mainly reduce costs and risks [12] [13].

Despite this potential, the high development overhead limits most VR training solutions today. Developing a custom training scenario is time-consuming and typically requires programming skills, 3D asset management, and platform-specific expertise [14], restricting the ability of domain experts (e.g., industrial trainers) to directly contribute to or modify training content. Some attempts have been made to propose authoring tools for this development. However, their inability to integrate CAD data, the common formats for modelling industrial equipment, hinders their potential to create authentic scenarios [15].

This paper presents a VR platform designed to bridge this gap. The system enables trainers to create, configure, and evaluate immersive training experiences entirely within VR. Using intuitive tools, trainers can construct realistic environments from CAD data and import their own objects to be interacted with. These can then be used to define procedural tasks without leaving the virtual space and with no programming experience required.

A relevant contribution of this work is the integration of *Virtual Choreographies* — a mechanism used to define, record, and validate user behaviors by storing these actions at a higher semantic level [1]. This allows trainees to be guided through structured procedures and enables an automated performance assessment.

## II. Related Work

This section reviews foundational research and systems relevant to immersive VR training, procedural modeling via *Virtual Choreographies*, and accessible XR authoring tools.

### A. Immersive VR Training

An immersive VR training platform is any tool that uses technology to create an immersive and interactive training experience through the use of virtually generated environments [2]. These environments replicate real-world scenarios allowing trainees to practice and be evaluated on their ability and knowledge to conduct specific tasks. It is hoped that this training can then be transferred to the physical world [3]. These platforms allow companies to train employees in a safe, controlled, and cost-effective environment [4], where even the most dangerous and unlikely scenarios can be explored.

Unfortunately, most VR training systems remain static, requiring professional developer input for each scenario [14], which limits scalability and excludes domain experts from the authoring process.

This limitation has previously been acknowledged in platforms such as VRTraining [6] [5], and has inspired several of the early design decisions in this work.

### B. Virtual Choreographies

Virtual choreographies are sets of actions linked to an environment that facilitate the understanding of said actions by using a higher semantic level [5]. Rather than handling pure raw data, they match action data with the context and

purpose in which they are applied [6]. They enable recorded actions to be translated into a more human-readable format, thus facilitating their study and analysis.

### C. VR authoring tools for non-experts

VR authoring tools for non-experts are platforms that allow users of a Virtual Reality platform to design and create realistic virtual environments intuitively and without the need for professional developer skills [6].

VR platforms, especially those designed for training, should be highly accessible to all users. This means allowing non-expert users to customize the content and environment to their needs [10].

These tools often allow users to add objects and manipulate the scene to make it as close as possible to a real-world scenario [9] [7]. Such tools enable software to be more generalized whilst allowing the end users to take advantage of it in a domain-specific way. This means that the software can be more easily kept up to date since users can adapt it as its objectives change over time. This avoids the creation of a very restricted system with scalability issues [11], and makes the software more appealing to a much broader audience.

## III. VR Training and Authoring Tool

This section describes the system developed to support the creation and delivery of immersive VR training scenarios by non-expert users (demo video [8]). The platform was designed to enable trainers to create immersive 3D training environments, define procedures and introduce documentation and procedure recordings, as well as assess trainee performance, all within a VR interface (Figure 1). At the same time, it leaves ample opportunity for a desktop application to be used for managing training courses and reducing VR-related fatigue.




Fig. 1. VR Training control bindings.

### A. Architecture

The system was developed in Unity 6.0 using the XR Interaction Toolkit (v3.1.1) and the OpenXR plugin, providing compatibility with a wide range of VR headsets (Figure 2). The modular architecture supports multiple execution modes (Authoring, Trainer Test, Practice, and Replay), each with specific tools and interfaces, accessible via an interactive menu [18]. Training courses are also subdivided into modules, procedures, steps, and actions, similarly to VRTraining [6], as seen in Figure 3.

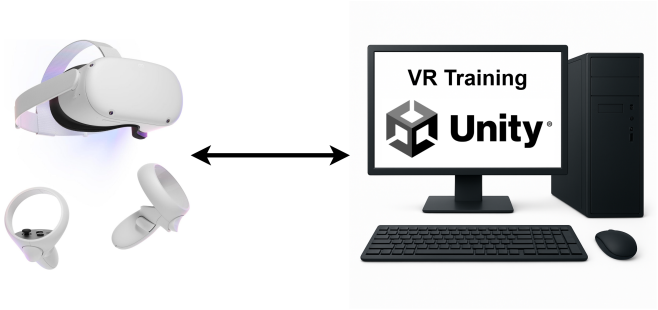



Fig. 2. VR Training environment.

Scenes are dynamically generated at runtime based on a JSON configuration file [10]. By compressing the experience into a configuration file, it is easier for trainers to share experiences with each other [17]. This file defines the training environment, initial object positions, user spawn location, and embedded documentation. Additional JSON files contain procedure steps to be performed by trainees, recordings of student attempts stored as *Virtual Choreographies*, and recording files to serve as data for the visual replay "as ghosts" mentioned in section III-F. The configuration file also allows content to be authored externally or updated in VR and then exported, thus enabling trainers to use a desktop tool to do part of the authoring, then refine and complete the training in VR, reducing the fatigue involved with VR usage [10].

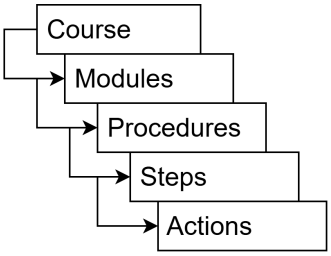



Fig. 3. Course structure.

### B. Environment Configuration

In Authoring Mode, users can define the spatial layout of the training scenario by placing, manipulating, and anchoring 3D objects and CAD data (props and interactables) [5] [6] that they can import into the system (Figure 4 and Figure 5). The integration of CAD data and 3D models is seen as a necessity and highly mentioned in the literature [6] [15] [9] [7]. Objects are loaded from a resource folder and placed using the included tools via a radial menu system designed for intuitive in-VR control (Figure 6).

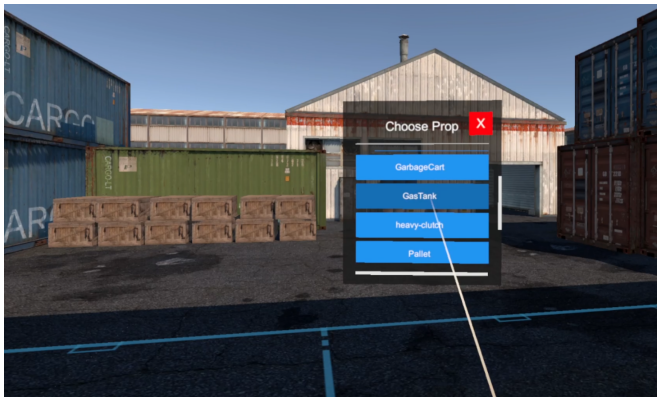



Fig. 4. Importing scene props.




Fig. 5. Importing interactable objects.




Fig. 6. Radial menu.

Users can fully customize the environment. The first step is to define the background, which can be anything, such as an empty warehouse or a complex, detailed 3D map.

With this foundation, trainers can populate the scene with props that make the course look more realistic, but also add objects to interact with. These objects can be positioned and scaled as desired [10] and they are assigned properties at runtime that enable them to be disassembled and reassembled at will. Visual guides aim to make this process much more intuitive.

Upon completion, the user can save the changes, which will be used to update the JSON file (Figure 6).

This process enables complete authoring of the training environment without leaving VR or writing code.

### C. Procedure Definition

The platform introduces a procedure definition workflow based on *Virtual Choreographies* [5]. Trainers can define a sequence of required actions, grouped into steps (Figure 8), such as grabbing and placing a specific object on a drop site, using a simple interface.


```
{
    "module": "Module_A",
    "procedure": "Procedure_X",
    "steps": [
        {
            "stepNumber": 1,
            "actions": [
                {
                    "timestamp": 266.0944519042969,
                    "verb": "drag",
                    "objectName": "Cylinder009",
                    "rootObject": "heavy-clutch_292090",
                    "prefabName": "heavy-clutch",
                    "extensions": {
                        "dropSite": "",
                        "position": {
                            "x": 0.0,
                            "y": 0.0,
                            "z": 0.0
                        }
                    }
                },
                {
                    "timestamp": 269.0992126464844,
                    "verb": "drop",
                    "objectName": "Cylinder009",
                    "rootObject": "heavy-clutch_292090",
                    "prefabName": "heavy-clutch",
                    "extensions": {
                        "dropSite": "DropZone_ea869d",
                        "position": {
                            "x": 84.238037109375,
                            "y": -0.23789334297180177,
                            "z": -4.221208572387695
                        }
                    }
                }
            ]
        }
    ]
}
```


Fig. 7. Procedure JSON.

The procedure definition tool allows trainers to:

- Associate tasks with scene objects.
- Define the expected action (e.g., grab, move, drop).

- Save the procedure as part of the environment configuration.

This procedure generates a *Virtual Choreography* stored in a JSON file (Figure 7), which will then be used to verify whether the actions trainees perform in the practice mode are correct.

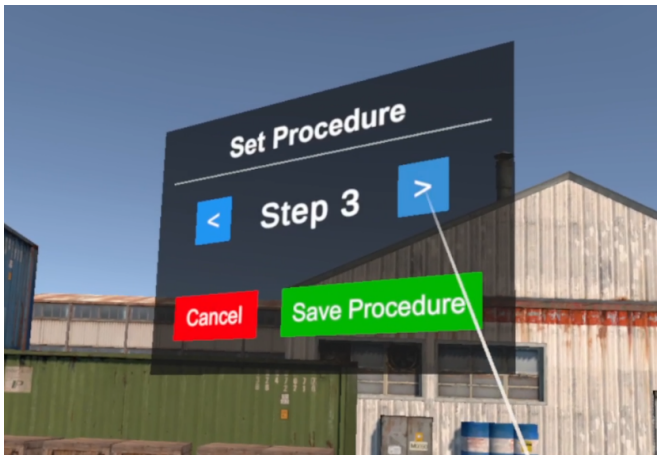



Fig. 8. Procedure definition.

### D. Procedure Recording

The system allows actions to be recorded in two different ways, which serve various purposes.

The first is fully recording movements and interactions to be replayed [16] [7] as mentioned in section III-F. This recording mode can be activated in the menu (Figure 9) and generates large JSON files containing multiple frames with the position of the controllers, the headset, and any objects grabbed [16]. The files are also named by their type, e.g., student recordings will have the prefix "Student_" while the default recording, which will be played in Practice Mode, will have the prefix "Def_"; this allows trainers to distinguish them in the Replay Mode.

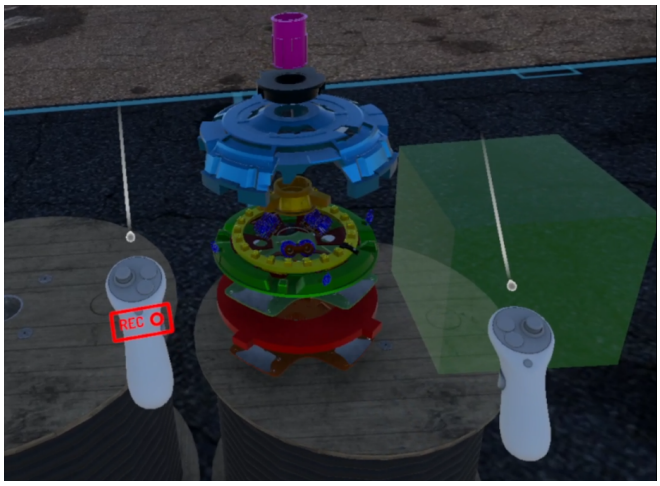



Fig. 9. Recording actions.

The second happens in the Practice Mode, where trainees' actions are automatically recorded and stored during the session as *Virtual Choreographies*(Figure 10) [6]. These recordings capture the moment when a user grabs a specific object and when they release it. The type of action is defined as 'drop' if the object is inside a designated drop zone, or 'released' if it is outside of a drop zone. In the latter case, the choreography also stores the object's new position.


```
{
    "module": "Module_A",
    "procedure": "Procedure_X",
    "totalActions": 2,
    "correctActions": 1,
    "wrongActions": 1,
    "stepsCompleted": 0,
    "totalSteps": 3,
    "steps": [],
    "flatActions": [
        {
            "timestamp": 173.80532836914063,
            "verb": "drag",
            "objectName": "Cylinder009",
            "rootObject": "heavy-clutch_292090",
            "prefabName": "heavy-clutch",
            "extensions": {
                "dropSite": "",
                "position": {
                    "x": 0.0,
                    "y": 0.0,
                    "z": 0.0
                }
            }
        },
        {
            "timestamp": 174.18020629882813,
            "verb": "release",
            "objectName": "Cylinder009",
            "rootObject": "heavy-clutch_292090",
            "prefabName": "heavy-clutch",
            "extensions": {
                "dropSite": "N/A",
                "position": {
                    "x": 79.83830261230469,
                    "y": 1.4029712677001954,
                    "z": -0.29289817810058596
                }
            }
        }
    ]
}
```


Fig. 10. Choreography of student attempt.

The recording system captures the object involved, the type

of action performed, the time and sequence of actions, and the position of the object released, as seen in Figure 10.

These recordings are stored and used for automated evaluation [5]. This format also allows trainers to inspect these choreographies manually and easily understand what the trainee did correctly or not [6].

### E. Virtual Choreography Checking

The platform implements a Virtual Choreography Checking system that compares recorded actions against the defined procedure [5]. the checking verifies whether or not the actions are performed as intended and in the correct order. For tracking where the object is dropped, the system checks if it is inside a drop zone or within a specific range of the position the trainer chose for the object to be placed. Both of these features can be assigned by the instructor.




Fig. 11. Realtime performance statistics.

The system also keeps track of the number of correct actions, the steps completed out of the total steps in the procedure, and the number of mistakes made during practice. Some of these statistics are available to the user while they perform the training (Figure 11), providing them with real-time feedback, and the full statistical summary is shown as an immersive UI panel when the user stops their current training attempt, seen in Figure 12.




Fig. 12. Attempt summary.

This automated evaluation helps learners and instructors to identify areas for improvement and reduces dependence on manual observation.

### F. Procedure Replay

Replay Mode enables trainers (or trainees) to visualize previously recorded sessions. Actions are re-enacted in sequence using ghost objects or animations [16] (Figure 13), allowing users to observe what was done, when, and in what order.



Fig. 13. Procedure replay.

This replay serves as a training review tool and a visual guide for trainees [16]. For trainers, it enables evaluation without direct supervision [15]. Students can record their attempts for their instructor to review later and provide crucial feedback. For trainees, it allows them to see a recording of their trainer showcasing how the procedure should be performed, in case they have any doubts about what to do [5] [16].

### G. Documentation Access

Inspired by the training platform, VRTraining [6] [5], and the positive feedback it received from users, a decision was made to include access to documentation. Trainers can add documents, such as PDF files with instructions or information

about the procedure, which trainees can then access [15], similar to what would happen in a real training scenario (Figure 14).

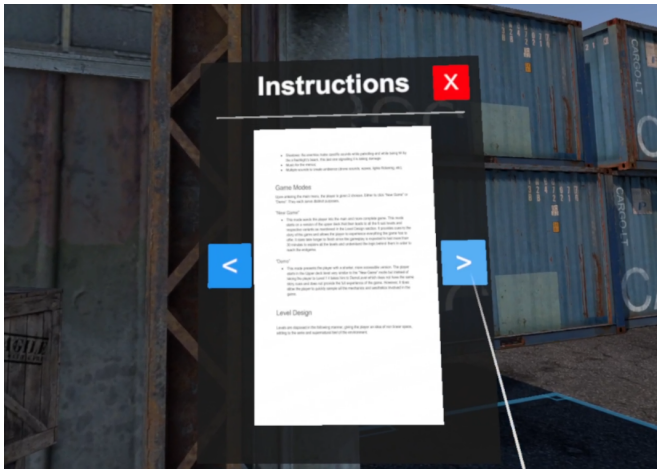



Fig. 14. Documentation access.

This addition empowers trainers with more tools to fully customize the training experience while giving trainees more information to learn from.

### H. Adjustable POV

Another contribution of this paper is the inclusion of a functionality to change the user's point of view (POV). This feature was inspired by interactive video demonstrations [7] where, on a desktop, trainers could move the camera around and show trainees areas that would not be accessible in a real scenario, such as viewing inaccessible or dangerous areas (e.g., radioactive sites) [19].

In the prototype system, users can use a "grab move" functionality where, by grabbing the trigger and grab button on their VR controllers, they can drag themselves in any direction, allowing them to view the scene from multiple angles with minimal motion sickness (Figure 15).

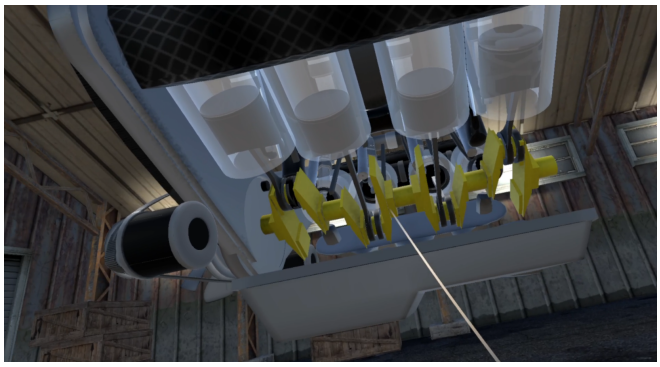


Fig. 15. Adjustable POV.

## IV. Usability Case Study

To evaluate the usability of the VR training and authoring platform, a user study involving 15 participants was conducted. Participants were asked to perform authoring and procedure practice tasks that would replicate the intended usage of the application. The test aimed at placing participants in both trainer and trainee roles and see how they felt about each one.

### A. Participants

The case study counted with 15 participants, most of them faculty members and students (12 of the 15), aged between 18 and 65 years. Their backgrounds were quite varied and they possessed no prior technical knowledge of industrial procedures. This was seen as an advantage since the platform should be accessible to everyone, regardless of their skill level. Even though 80% of participants had some type of previous contact with VR headsets, the other 20% shared similar feedback, not being affected by this.

### B. Method

The study conducted was a supervised practical test, where users interacted with the application to perform a series of tasks, with a duration between 10 and 20 minutes, depending on the level of participant engagement and exploration. Their attempts were closely monitored, and tips were provided when needed. However, when this happened, a log entry was added to mention what made them require a hint.

After the practical test, participants were asked to fill out a form with 3 sections: 1) basic questions about their demographic and VR experience (e.g., age and prior VR contact); 2) a series of questions with Likert-scale ratings (1–5); 3) a few open-ended questions to provide feedback.

### C. Tasks

When starting the test, participants were asked to play around with the movement mechanics and basic object handling, in order to understand the basis of the platform. Then, they were asked to take on the role of a trainer and configure a training environment by adding a few props and objects to interact with. They would also explore the feature to define a new procedure. Afterwards, they would take on the role of a novice trainee attempting a simple procedure for the first time. For this, they would have to access a document with instructions and use the video replay to see how the procedure had to be done. With this information, they were asked to attempt the procedure without any mistakes.

### D. Results

*1) **Ease of Use**:* Most users (12) rated task difficulty between 4 and 5 (5 = Very Easy), indicating strong usability across the system's main features. Tasks such as grabbing/moving objects and using the menu were consistently described as intuitive despite some subjective suggestions for improvement.

*2) **Challenges**:* Despite the positive feedback, some participants (6) indicated that the defined control bindings for rotating and scaling objects were not intuitive and conflicted with the camera's snap turn functionality. The menu bindings were also seen as complicated by 5 users. It was also observed

that the platform involved a slight learning curve, especially for users unfamiliar with video game controllers.

A lack of visual confirmation for specific actions was also noted by 4 participants, where participants could not identify whether a particular action had been completed or even in which mode they were currently in.

As is common with VR platforms, motion sickness remains an issue for a minority of users (3). Also, the feedback provided suggests some features, such as a slow speed for the "grab move" feature or the teleportation mode, helped reduce motion sickness.

### *E. Case Study Conclusion*

All participants stated they could use the platform to create training content with minimal guidance and practice procedures without consequences. Responses highlighted the system's accessibility and potential, especially when minor usability issues are addressed.

## V. Limitations

While the proposed platform demonstrates strong potential for accessible VR training authoring, several limitations remain:

- **No Collaborative Functionality:** The system is currently designed for single-user sessions. Multi-user collaboration — including real-time trainer-trainee interaction — is not yet supported, but could be an effective addition to improve the quality of training.
- **Limited Input Modalities:** Voice commands and voice recordings are not implemented. This limits the realism of certain training tasks, especially those involving verbal procedures or communication.
- **Fixed Asset Library:** All available props and interactable objects must be pre-loaded into the prototype system. A complete version should support runtime import of external CAD models or user-provided assets.
- **VR-Only Authoring:** Trainers must use a VR headset to configure scenarios. Although JSON files can be edited manually, there is currently no desktop authoring interface for trainers who prefer non-immersive environments.
- **Simplified Choreography Checking:** The choreography validation tool is order-sensitive but does not yet handle complex logic such as conditional branches, timing constraints, or parallel tasks.
- **Motion Sickness:** Despite the efforts to combat motion sickness, for some users, even short VR exposure can cause some discomfort.
- **Tutorial:** A few users (3) felt the need for an interactive onboarding/tutorial system to soften the platform's learning curve [18].
- **Unintuitive Object Manipulation:** Rotation and resizing controls were cited as unintuitive, limiting precise scene configuration and causing user frustration.

These limitations are mostly technical rather than conceptual and can be addressed in future iterations.

## VI. Future Work

Considering the current prototype and the research conducted, some steps could be taken to improve the application's functionality, usability, and training effectiveness.

- **Desktop Authoring Interface:** A companion desktop application could be developed to allow trainers to configure environments and procedures without entering VR. This would reduce the exhaustion involved with VR usage and bypass typical VR annoyances such as the use of VR keyboards, since text inputs could be added in desktop mode and accessed later in VR.
- **Collaboration and Networking:** Support for multi-user sessions will enable trainers to supervise trainees remotely or conduct joint sessions.
- **Voice Integration:** Adding support for voice guidance, narration, and voice-based evaluation could enhance immersion and task realism [5].
- **Asset Import Pipeline:** Runtime support for importing CAD or common 3D file formats will make the system applicable in real industrial settings.
- **Advanced Choreography Logic:** Future versions could support conditional flows, optional steps, and error recovery mechanisms in action sequences.
- **Formal Evaluation:** A larger-scale user study with professional trainers and real trainees should be conducted to evaluate learning effectiveness and long-term usability [17].
- **Tutorial:** The platform could benefit from an animated tutorial to facilitate the experience for new users [18].
- **Procedure Descriptions:** Including textual descriptions of procedures within the VR scene could help users understand what they are actively doing, leading to a more effective learning process.
- **Virtual Choreography to PDF:** The current choreography system could be used to convert attempt reports into detailed PDF files with clear descriptions of what was done, enabling trainers to simply read a report of their student's performance.
- **Enhanced Object Manipulation Tools:** Adding visual rotation guides, snapping systems, or more intuitive scaling methods would reduce setup errors and improve precision.

Research shows [20] that the phenomenon of Immersion arises not only by users begin visually envoloped by virtual environments, but also in combination with the meaning of the events and goals (the narrative dimension), and by the plausibility of the range of experiences available and the range of interaction options (the agency dimension). We aim to expand the authoring tool to encompass these aspects, linking it to learning management systems and overall learning planning tools.

## VII. Conclusion

This paper presented a VR-based training platform that allows non-expert users to author, execute, and evaluate immersive training scenarios. The system supports complete

setup of the virtual reality environment, procedure definition, recording and replay of user actions, and structured performance evaluation using *Virtual Choreographies*.

Designed with accessibility in mind, the platform uses intuitive interfaces, such as radial menus, control hints, and configuration files to reduce the learning curve for domain experts. A user testing session confirmed the usability and functionality of the platform, while also identifying areas for improvement.

The integration of procedure recording, replay, automated validation, and the ability to use the platform to create and update training scenarios without professional developer skills distinguishes this work from many VR training solutions that require manual supervision or development expertise. The system provides a foundation for future extensions, including collaborative training, voice interaction, and desktop-based authoring, with the long-term goal of supporting scalable, customizable training across domains.

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## A.2 Script used for User Testing

# VRTraining2.0 - User Testing Script

Thank you for participating in this user testing session. You will be interacting with a prototype of a VR-based training platform designed to allow trainers to create, test, and deliver immersive training scenarios without requiring programming knowledge.

This test is part of a university research project, and your feedback will help evaluate the usability, clarity, and functionality of the system. During the session, you will be asked to follow this script to explore the main features of the platform, including scene authoring, procedure creation, recording, and replay functionalities.

Now that you have completed the interaction, please answer the following questions based on your experience. Your responses will remain anonymous and will be used solely to guide further development and research conclusions.

There are no right or wrong answers — please be honest and detailed in your feedback.

Thank you again for your time and valuable input.

**SETUP:**

- Load the config file with the heavy clutch and dropzone.
- Initialize the app with the config file in Authoring Mode.

## Upon Starting:

- Experiment with movement options (teleport, continuous, grab move)
- Open and close the menu
- View hints

## Authoring Mode:

- Update the Spawn Position
- Add one Prop object
- Add one Interactable Object
- Save Scene
- Switch to Trainer Test Mode

## Trainer Test Mode:

- Documents: open “UserTesting-Instructions”
- Training->Set Procedure
- Follow the steps in the document, increment the step number after each action
- Save Procedure
- Reset Scene
- Switch to Practice Mode

## Practice Mode:

- Open the procedure documentation if needed
- VideoGuide->Play
- Watch the ghost performing actions
- VideoGuide->Clear
- Start Recording actions
- Perform the 3 step procedure again
- Perform a 4th incorrect step to add at least one mistake
- Stop recording
- Stop the current procedure attempt
- View the attempt summary
- Switch to Replay Mode

## Replay Mode:

- Select Recording
- Play one of the available recordings

# Thats it

Explore the system freely

# VRTraining2.0 - User Testing Script Short Version

**SETUP:**

- Load the config file with the heavy clutch and dropzone.
- Initialize the app with the config file in Authoring Mode.

## Upon Starting:

- Experiment with movement options (teleport, continuous, grab move)
- Open and close the menu
- View hints

## Authoring Mode:

- Play around with the models in the scene
- Switch to Practice Mode

## Practice Mode:

- Menu->Documents: open “UserTesting-Instructions”
- VideoGuide->Play
- Watch the ghost performing actions
- VideoGuide->Clear
- Start Recording actions
- Perform the 3 step procedure displayed
- Perform a 4th incorrect step to add at least one mistake
- Stop recording
- Stop the current procedure attempt
- View the attempt summary

## A.3 Procedure Instructions provided during User Testing

# VRTraining2.0 - Procedure

## Step 1:

- Grab the Clutch Actuator (Purple)
- Drop it in the drop site

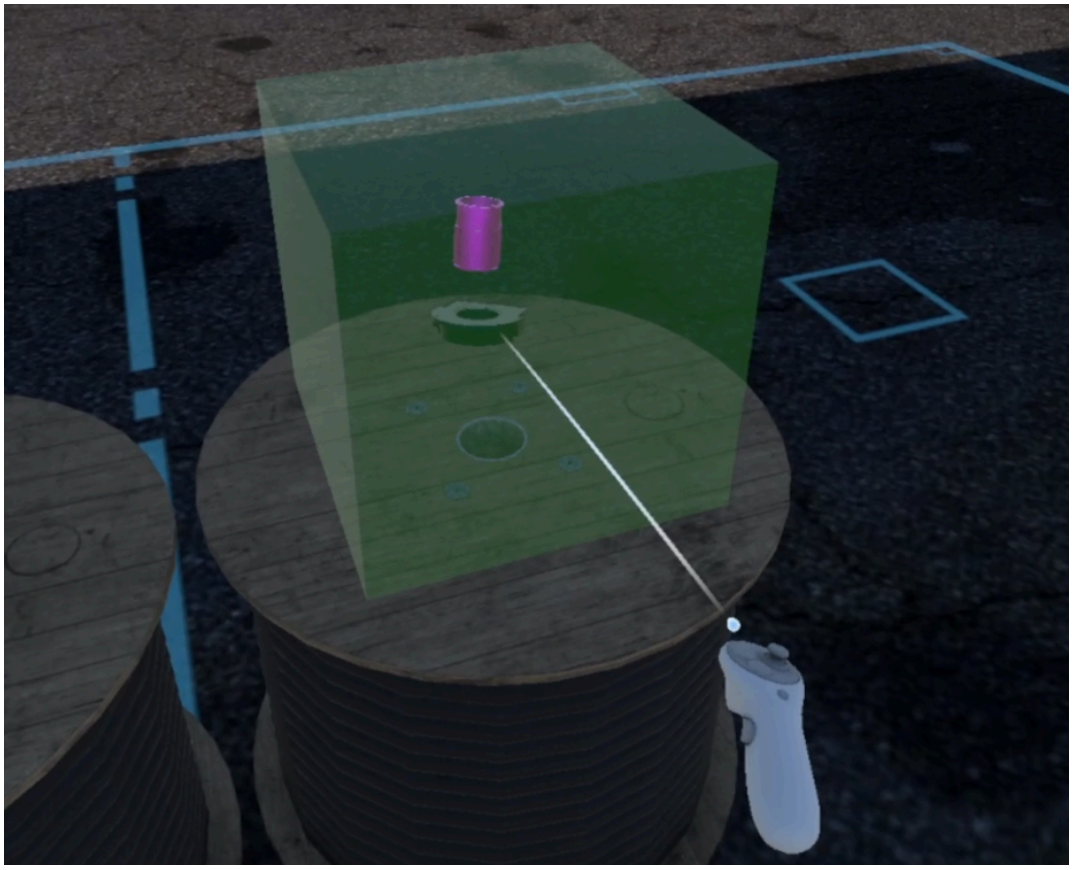




# Step 2:

- Grab the Pressure Plate (Black)
- Drop it in the drop site

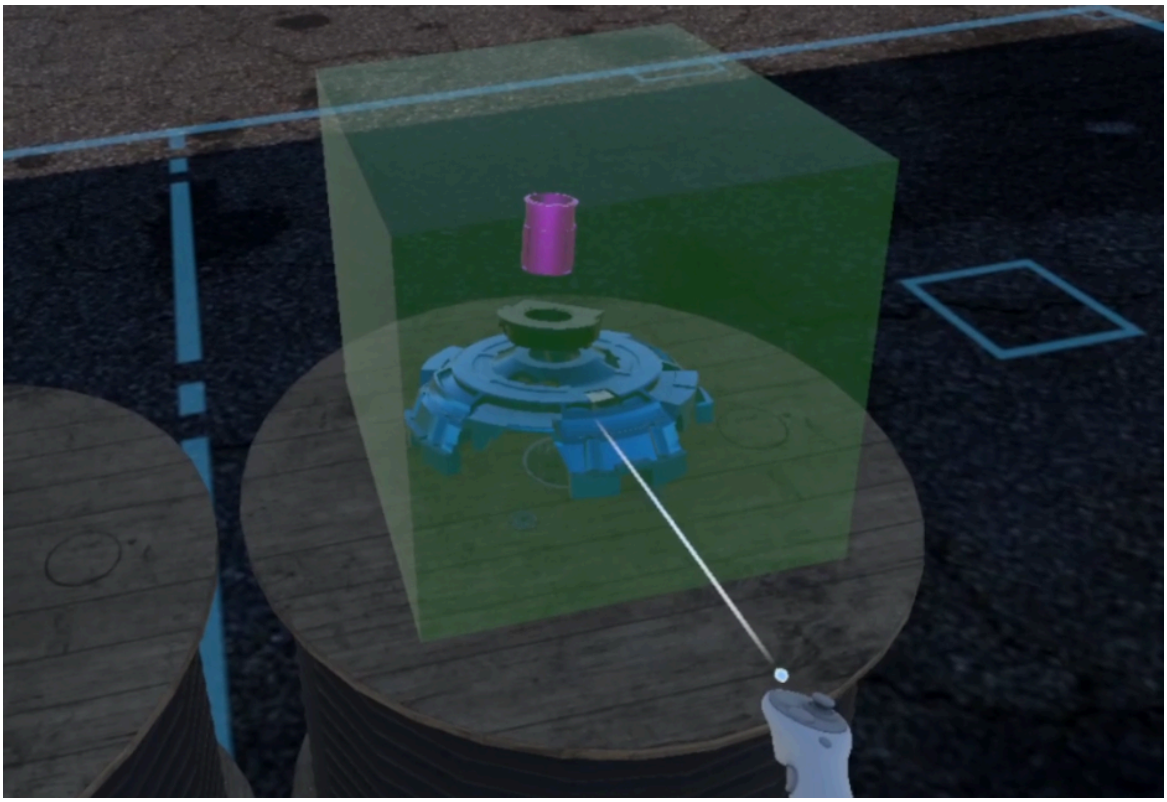




# Step 3:

- Grab the Clutch Housing (Blue)
- Drop it in the drop site





## A.4 User Testing Questionnaire

# User Testing for a VR Training and Authoring Tool

Thank you for completing the user testing session.

The prototype you interacted with is part of my Master's thesis project focused on developing an immersive and accessible Virtual Reality (VR) Training and Authoring platform. The system aims to enable trainers to design and deliver hands-on training scenarios directly within VR — without requiring programming or development expertise.

You have just experienced a guided walkthrough of the platform's main features, including environment setup, object manipulation, training procedure creation, and replay functionalities.

This questionnaire is designed to capture your feedback on:

- Usability of the system;
- Clarity and discoverability of features;
- Your confidence in completing key tasks;
- Suggestions or frustrations you encountered.

Your responses are anonymous and will be used solely for academic analysis and to guide future improvements to the platform. Please answer honestly and in as much detail as you feel comfortable — even brief comments are highly valuable.

Once again, thank you for contributing to this research. Your input is essential to evaluating the effectiveness and future potential of this VR training system.

* Indica uma pergunta obrigatória

1. Testing Number (Given to you during the demo)

2. How old are you ?

   *Marcar apenas uma oval.*

   - ◯ <18
   - ◯ 18-25
   - ◯ 26-35
   - ◯ 35-65
   - ◯ >70

3. Have you used VR before ? *

*Marcar apenas uma oval.*

- Yes
- No

4. Are you used to videogame controllers ? *

*Marcar apenas uma oval.*

- Yes
- No

Task-Specific Ratings (Rate from 1 = Very Difficult to 5 = Very Easy

If you did not perform the actions mentioned in a specific question you can leave it empty.

5. Setting a new spawn point

*Marcar apenas uma oval.*

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| Very | ◯ | ◯ | ◯ | ◯ | ◯ | Very Easy |

6. Importing and manipulating objects

*Marcar apenas uma oval.*

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| Very | ◯ | ◯ | ◯ | ◯ | ◯ | Very Easy |

7. Using the radial menu

*Marcar apenas uma oval.*

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| Very | ◯ | ◯ | ◯ | ◯ | ◯ | Very Easy |

8. Defining procedure steps

*Marcar apenas uma oval.*

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| Very | ◯ | ◯ | ◯ | ◯ | ◯ | Very Easy |

9. Switchinig between the 4 different modes

*Marcar apenas uma oval.*

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| Very | ◯ | ◯ | ◯ | ◯ | ◯ | Very Easy |

10. Understanding control bindings

*Marcar apenas uma oval.*

| | 1 | 2 | 3 | 4 | 5 | |
|---|---|---|---|---|---|---|
| Very | ◯ | ◯ | ◯ | ◯ | ◯ | Very Easy |

## Open-Ended Questions

These questions are useful for identifying more unique aspects from your experience.

11. What did you find easiest to do ?

12. What did you find confusing or frustrating ?

13. Was motion sickness an issue for you ? *

14. Were there any features you expected but did not see ?

15. Do you feel you could use this platform to create a training course with minimal guidance ? Why or why not ?

16. Any other feedback or suggestions ?

Este conteúdo não foi criado nem aprovado pela Google.

Google Formulários

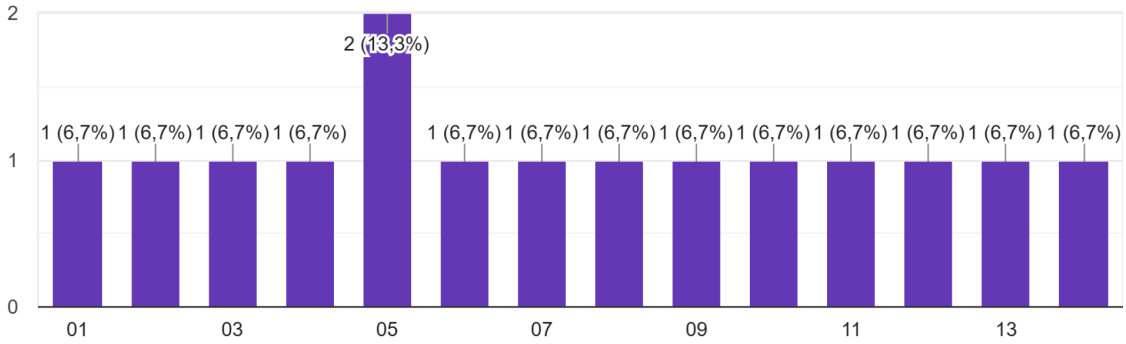
## A.5 Answers to the User Testing Questionnaire

# VR Training - Questionnaire Answers

## Demographic Questions:

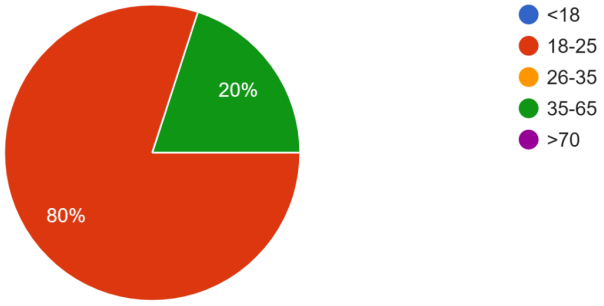
Testing Number (Given to you during the demo)

15 respostas



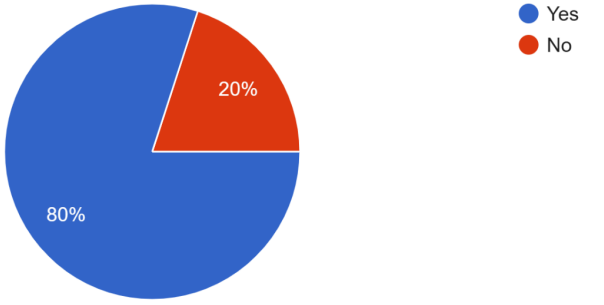

How old are you ?

15 respostas



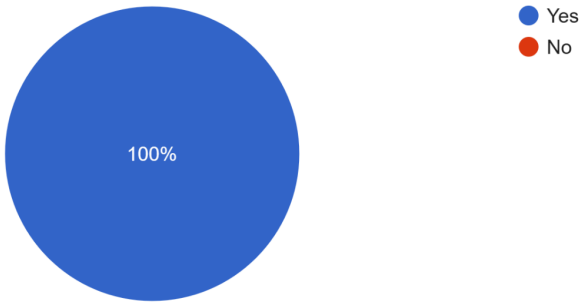

Have you used VR before ?

15 respostas



Are you used to videogame controllers ?

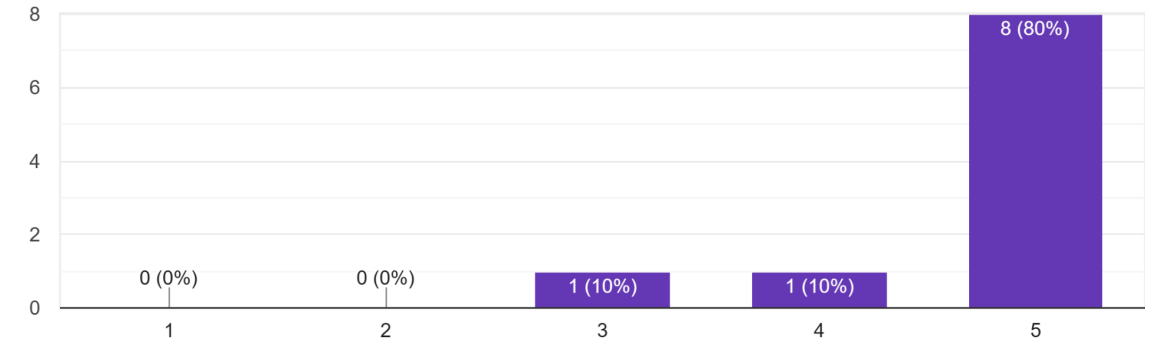
11 respostas




# Task-Specific Ratings (Rate from 1 = Very Difficult to 5 = Very Easy

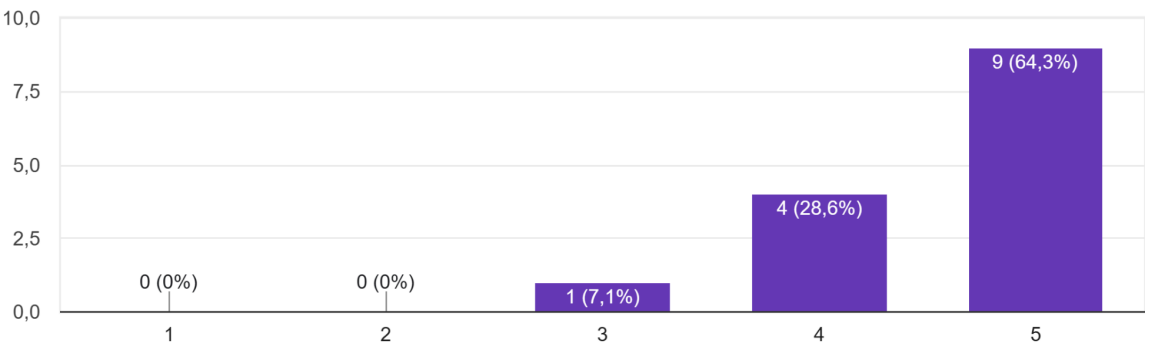
Setting a new spawn point

10 respostas



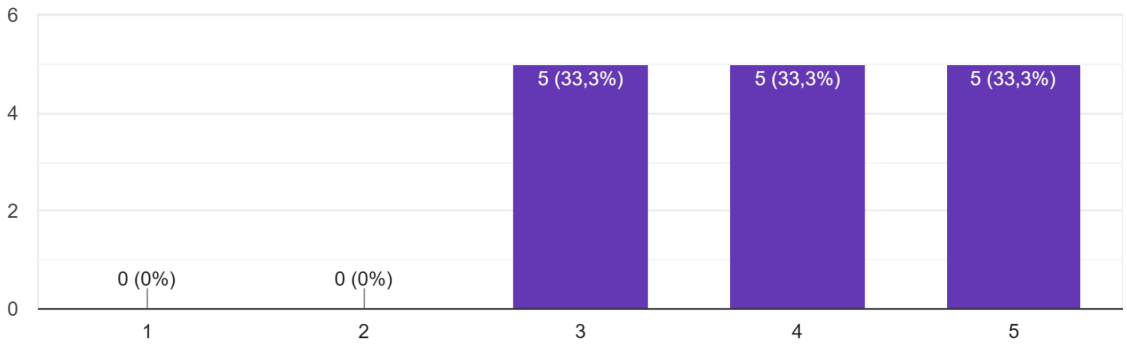

Importing and manipulating objects

14 respostas



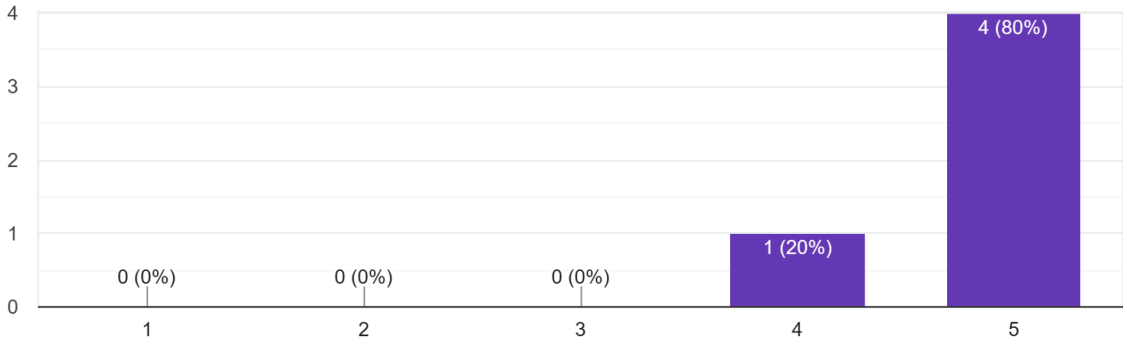
## Using the radial menu

15 respostas



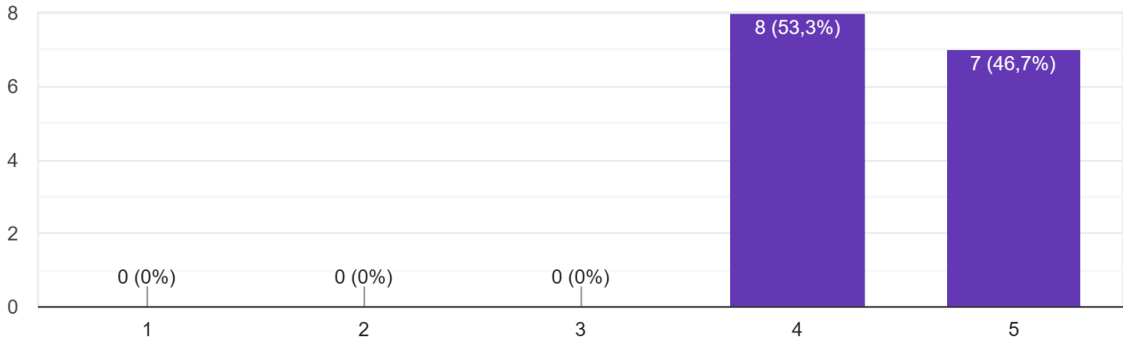

## Defining procedure steps

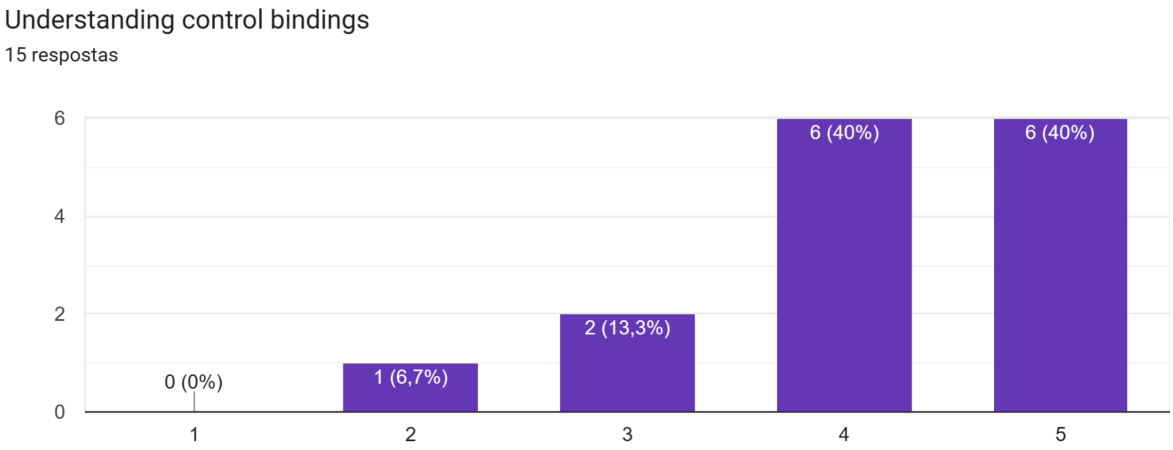
5 respostas




## Switchinig between the 4 different modes

15 respostas






## Open-Ended Questions

| Answers | What did you find easiest to do ? |
|---|---|
| A01 | Move objects. |
| A02 | Moving the objects |
| A03 | walk |
| A04 | Manipulating the objects. |
| A05 | Grabing and Interacting with objects felt pretty intuitive |
| A06 | por as peças por ordem |
| A07 | walk and look around, simple console presses (one button presses) |
| A08 | Teleport to a specific place or remove / put objects in the right place. |
| A09 | It was very intuitive to understand the mechanics and how everything works in the environment |
| A10 | easy to grab objects, to walk around and to get new objects in the field. |
| A11 | Grab and move an object |
| A12 | usar o menu |
| A13 | Creating the procedures and instantiating the manipulated models, as well as grabbing and dropping components into the dropbox. |

| Answers | What did you find confusing or frustrating ? |
|---|---|
| A01 | rodar as peças |
| A02 | Object rotation because it moves in one acis with the analog and in another with the rotation of the wrist. |
| A03 | The menu, having to press the joystick button |
| A04 | a seleçao, ou com gatilho ou com o botao no joystick |
| A05 | I found the control bindings confusing because I'm not used to it. |
| A06 | Reading the text in the radial menus if they were slightly rotated |
| A07 | Some button bindings, rotating objects and some graphics (harder to depict if not from up close) |
| A08 | Could not read so well the instructions |
| A09 | nothing really to point out |
| A10 | needing to click in the "r3" of the controller to select in the menu instead of a button. |
| A11 | The resizing keybind felt a bit unintuative |
| A12 | Rotating the objects in a specific angle. |
| A13 | authoring tool procedure creation |
| A14 | N/A |
| A15 | N/A |

| Answers | Was motion sickness an issue for you ? |
|---|---|
| A01 | Sometimes |
| A02 | Yes |
| A03 | no |
| A04 | moderado |
| A05 | No, but my lack of vr experience does make moving arround with the stick feel a little odd |
| A06 | A little bit stange but easy to adapt. |
| A07 | Yes, but I get motion sick very easily |
| A08 | não |

| | |
|---|---|
| A09 | some times, but using the teleport make it easier |
| A10 | N/A |
| A11 | N/A |
| A12 | N/A |
| A13 | N/A |
| A14 | N/A |
| A15 | N/A |

| **Answers** | **Were there any features you expected but did not see ?** |
|---|---|
| A01 | No. |
| A02 | No. |
| A03 | Sound feedback |
| A04 | não |
| A05 | physics |
| A06 | A tutorial maybe |
| A07 | nao |
| A08 | A textual description of the procedures could be useful. Each step or action should include a descriptor in the UI, such as 'Grab piece B from object A'. |
| A09 | Yes, creating procedures with feedback when the system identifies behaviours |
| A10 | N/A |
| A11 | N/A |
| A12 | N/A |
| A13 | N/A |
| A14 | N/A |
| A15 | N/A |

| Answers | Do you feel you could use this platform to create a training course with minimal guidance ? Why or why not ? |
|---|---|
| A01 | sim |
| A02 | Yes, after exploring the features for some time I certainly could, although a guided tutorial in the beginning would help a lot. |
| A03 | Yes, the platform seems complete enough to create complex movements in various different contexts |
| A04 | definitivamente |
| A05 | Yes, I think it has a lot of instructions and the video-guide is really usefull. And I found easy to identify and select the objects, through the colour and shape and they are all diferent and specific. |
| A06 | Yes, with a more linear approach. Since it uses real life concepts and it since it mimicks real life procedures |
| A07 | yes, with more budget, this can have better graphics for the smaller pieces and easier controls |
| A08 | Yes. It was intuitive grabing objects and put them back with the help of the placeholders |
| A09 | Yes the ambient allows for interacting with objects that can be rather tricky irl so training in vr sounds really interesting |
| A10 | for sure and a very fun way to do it as well |
| A11 | Yes, it is accessible and more representative of he task then a video. Especially because you can watch a "recording" of someone else doing it. |
| A12 | I found the entire process intuitive and highly accessible for creating training courses, without requiring extensive training to learn how to use the platform. I can even picture it being useful in other use cases beyond the one explored during testing. |
| A13 | Yes |
| A14 | N/A |
| A15 | N/A |

| Answers | Any other feedback or suggestions ? |
|---|---|
| A01 | Some button remapping. |
| A02 | The button to interact with the menu should not be pressing the joystick button, it could be pressing the trigger for example, as that would be more intuitive.<br>The display window (for opening the instructions for example) could be bigger, as it isn't very easy to see. |

| | |
|---|---|
| A03 | It would be interesting to learn about the function of the objects - what are they for? We can identify the colour and the shape of them, but I would like to know what they do in practise. And maybe it would be possible to have some calm background sounds. |
| A04 | Audio implementation would make the enviornment feel less empty and it could positively affect feedback during tasks |
| A05 | não |
| A06 | Switch the select button in the menu |
| A07 | No |
| A08 | maybe try to add more models of pieces to put in the app |
| A09 | acho que pode ser aplicado a outras áreas |
| A10 | Automatically generating PDF files that describe procedures could be useful for teachers. After creating a procedure, they could easily produce supplementary materials to distribute to students.<br>Add shortcuts for certain actions. For example, instead of navigating through the menu to select a spawn point, include a command binding shortcut to enter that mode directly. This approach could also be extended to other frequently used actions. |
| A11 | Mainly work on the user feedback |
| A12 | N/A |
| A13 | N/A |
| A14 | N/A |
| A15 | N/A |