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Virtual Reality System for Inspection and Training: A case study in Wheel-Loader Operations

Luiz Felipe Muniz Rocha Borges [**Federal Institute of Espírito Santo** | ***luizfelipemrb@gmail.com***]
Arthur Spinassé Miranda [**Federal Institute of Espírito Santo** | ***arthurspinassemiranda@gmail.com***]
João Vitor Ladislau Ferreira [**Federal Institute of Espírito Santo** | ***joaovitorladislau@gmail.com***]
Thales Pinheiro Lazarini [**Federal Institute of Espírito Santo** | ***thaleslazarini2003@gmail.com***]
Alexandre De Angeli Neto [**Federal Institute of Espírito Santo** | ***alexandre.deangelineto@gmail.com***]
Matheus Gianordoli Novais [**Federal Institute of Espírito Santo** | ***matheusgianordoli@gmail.com***]
Marcelo Queiroz Schimidt [**Federal Institute of Espírito Santo** | ***mqschimidt@gmail.com***]
Rodrigo Varejão Andreão [**Federal Institute of Espírito Santo** | ***rvandreao@gmail.com***]
Mário Mestria ✉ [**Federal Institute of Espírito Santo** | ***mmestria@uol.com.br***]

✉ *Coordinating of Electrical Engineering, Federal Institute of Espírito Santo, Av. Vitória, n. 1729 - Jucutuquara, Vitória, ES, 29040-780, Brazil,* `https://ror.org/05rshs160`.

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Abstract: A virtual-reality-based serious game to inspect and train a wheel loader is proposed in this paper. The game is developed using a cross-platform game engine and it is integrated into various virtual reality (VR) headsets. The proposed game was conducted under inspection and training procedures on the wheel loader of a mining company with elements to engage field workers. The results reached demonstrated the benefits of the use of such implemented technology. In addition, 16 workers assessed the game and completed a survey. The survey results suggest that the system can be used for staff training before handling a real wheel loader in a mining company. The findings suggest that the implementation of a game for inspection and training improves the process, reduces expenses, and improves safety. The game favors the development of technical skills required for real-world procedures. The VR serious game proposed as a training tool prepares company staff for inspection and operating on a wheel loader. The serious game can be expanded to include various technical procedures, such as a maintenance procedure for a tamping machine.

Keywords: Virtual reality, Serious game, Training, Inspection virtual environment, User interface game, Industry 4.0.

1 Introduction

Virtual reality (VR) provides users with multiple intuitive sensations while simulating mechanisms in physical or imaginary worlds, integrating multimedia, sensors, displays, human–machine interaction, ergonomics, simulation, and computer graphics Guo *et al*. [2020]. Some VR technologies enable an immersive experience through interactions with generated virtual environments Zhu *et al*. [2019]. In recent years, several studies have been conducted in various fields using VR technology, attracting considerable interest in both academic and other fields.

Serious games are video games aimed at problem solving rather than entertainment. A VR-based serious game application offers a new learning medium that holds special interest for simulation and can be applied for immersive and procedural simulation Pilote and Chiniara [2019]; Luz Melo *et al*. [2025]; Malpartida and Rodrigues [2025].

This technology covers a wide range of economic sectors, including manufacturing industries and healthcare Ali *et al*. [2023], the mining industry Borges *et al*. [2024]; Ribeiro de Oliveira *et al*. [2020], tourism Sancho-Esper *et al*. [2023], health Rahman *et al*. [2024], game technologies Korkut and Surer [2023], education Radianti *et al*. [2020]; Shao-Chen Chang and yung Jong [2020], inspections of airplanes Eschen *et al*. [2018] and simulations, such as an anatomy system applied to learning Wang and Wang [2018]. In Corso *et al*. [2017], a serious game was developed for users to paint three-dimensional (3D) models with real measured materials, simulating the physical world. The objective of VR in these areas is to improve learning, training, virtual inspection of objects, and immersive experiences.

A potential benefit of the VR-based serious game is that it improves work safety in the industrial environment, attracting increasing attention from public opinion and policymakers. Another study designed training programs to teach employees about the risks and requirements of safety procedures Joshi *et al*. [2021]. These training tasks include corrective actions to prevent accidents or injuries. In addition, industrial managers are interested in digital games for training in the industry, with the purpose of training in risk situations in the industry Rufino Júnior *et al*. [2023].

However, safety instructions and procedures vary between applications, and their potential benefits must be validated through user experience evaluation. This study addresses the challenge of building a VR-based serious game simulator for inspection and training in the wheel loader of one of the world's largest mining companies.

A wheel loader is an off-road tractor with two distinct units connected by a pin-joint: the front unit, which has a robotic manipulator, and the rear unit, which contains drivetrain components, an engine, and the driver's cabin Dadhich

[2018].

Despite conventional training methods being effective, they are often insufficient for instructing operators in all dangerous scenarios. These methods do not provide operators with a real-life impression of all situations. Therefore, the developed serious game enables effective training by providing operators with a sense of realism in dangerous scenarios.

Furthermore, the serious game can be extended to include other types of procedures with a diversity of scenarios. This study introduces important considerations that can promote economic and social impact; the serious game allows for training before the real equipment is used.

This work attempts to address the following research question: *Does a VR-based system facilitate learning how to inspect and operate a wheel loader for professional collaborators without prior knowledge of the procedures?* The system and methodology to answer this research question are presented in this study.

The remainder of this paper is organized as follows. Sections 2 and 3 present the related work and a virtual system for inspection and training applied to a wheel loader, respectively. Sections 4 and 5 describe the virtual system and demonstrate the materials and methods, respectively. The computational results are presented in Section 6. Section 7 discusses the findings, the ethical considerations, challenges and reproducibility of the proposed work. Finally, conclusions and future work are reported in Section 8.

2 Related Work

Literature on VR and serious games inspired the development of a new serious game that addresses a research problem related to training and inspection. The serious game can provide efficient training, reduce costs, and aid in implementing Industry 4.0.

2.1 Virtual Reality

Implementing VR simulators or serious game as learning methods has become essential for areas involving high-risk procedures. Such simulators are important in circumstances where workers need prior knowledge to execute their jobs Wang and Wang [2018] effectively. For instance, universities spend considerable time and resources using cadavers to teach assignments; these issues can be avoided using VR simulators as an introductory method. Despite the advantages of the VR system, the university cannot fully replace traditional learning methods because the simulator developed by the authors cannot cover the entire context in which it is applied.

The authors in Sinnott *et al*. [2019] improved NASA's Neutral Buoyancy Training by using VR simulators aided with a breathing apparatus. Similar to the study by Wang and Wang [2018], which aimed to reduce wasted time and resources, the authors in Sinnott *et al*. [2019] suggested using VR simulators. They developed a virtual environment that enables workers to learn how to perform their jobs. A study involving nine participants proved that the system developed by the authors performed similarly to NASA's system at a fraction of the cost, achieving the goal of the project.

The project developed in Tsai *et al*. [2017] shows how VR technology can be employed as a tool to improve effectiveness in sports training, specifically basketball, highlighting wide range applicability of VR. Off the basketball court, every detail matters, similar to industrial inspections. Data processing generated from these systems, helped by computers, is accurate and scalable, improving results wherever it is used. System survey results Tsai *et al*. [2017] indicate a better user experience compared to conventional physical basketball tactical boards, suggesting that VR can be effective tool for enhancing training effectiveness.

In addition to learning methods, VR simulators can be utilized as psychological tools for establishing certain behaviors. Immersive and realistic simulations based on VR technology have been proposed for monitoring human-following behavior as a new type of redirected walking system (Nguyen *et al*. [2020]). Users tended to adapt their trajectories to match the path of the agent. With this technology, new simulators in workplace safety can be developed using the results of the authors.

According to Soori *et al*. [2024], virtual manufacturing, computer simulations, and models are used for designing and optimizing manufacturing processes and products. They help businesses build products faster and more affordably by testing their ideas in a virtual setting before spending money on prototypes.

The work of Ribeiro de Oliveira *et al*. [2023] underlines how VR-based applications can improve human–machine interactions by adopting artificial intelligence methods, especially in scenarios involving intelligent robotic technologies. Despite this benefit, employees still require a set of digital skills necessary for operating such technology Štaffenová and Kucharčíková [2024].

In Akpan and Offodile [2024], the authors examined the role of VR simulations in manufacturing through the science mapping method. Their analysis of the conceptual structure of the literature highlights the contexts, applications, and relevance of VR simulation in the Industry 4.0 era. This simulation plays a potent role in digital twins, predictive maintenance, additive manufacturing, 3D printing, virtual manufacturing, and the immersive simulation of virtual digital industrial unit.

In Javaid *et al*. [2022], the authors highlighted two key points: (1) the connection between individuals, devices, and data in new ways and their interactions is influenced by technology development, including artificial intelligence, VR, and the internet of things (IoT). Furthermore, (2) producers can demonstrate their goods or processes to consumers in a simulated world using VR in manufacturing systems and installation lines at the plant.

The fourth industrial revolution, or Industry 4.0, is a term used to define a new generation of manufacturing, factories, and business processes based on a set of key-enabling technologies, such as sensor networks, IoT, cloud computing, 3D printing, advanced robotics, VR, and artificial intelligence Commission [2018]; Romero-Gázquez *et al*. [2022]. This revolution is also moving toward the automation and digital transformation of the manufacturing environment. The technological pillars of Industry 4.0 are shown in Figure 1.

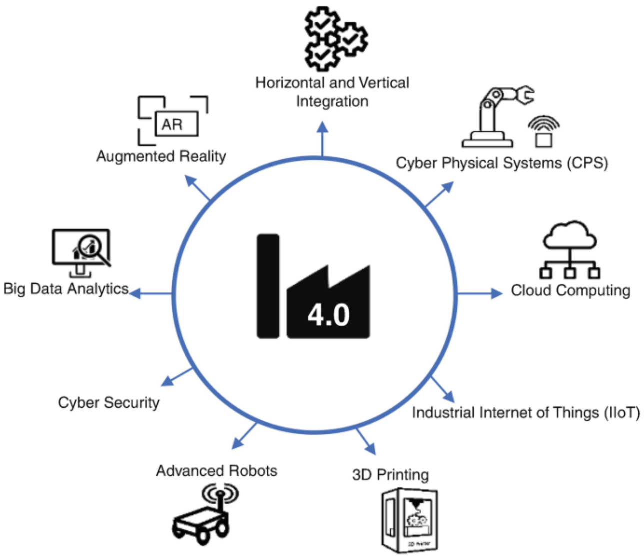

Figure 1. Technological pillars of Industry 4.0, adapted from Alaloul *et al.* [2022]

2.2 Serious Game

A serious game is an intelligent process applied in industry, marketing, logistics, production, and supply chains. It is defined as an intelligent system developed using the same tools as a conventional video game, but it is targeted toward specific ends that transcend the playful aspect of the game Mitgutsch and Alvarado [2012]. Examples includes improving mental health and preventing disorders Schoneveld *et al.* [2018], boosting the confidence and treatment desire in children suffering from anxiety disorders, and undergoing cognitive-behavioral therapy.

According to Hess and Gunter [2011], a serious game can help with learning as a complimentary tool for an online American history course. In this study, the aim is to aid staff training in a work environment through a VR-based serious game. This technology can be used as a complimentary tool with state-of-the-art training procedures, particularly for generating distinct scenarios with varying degrees of complexity.

Owing to the similar development methods, a serious game can inherit key requirements of its recreational counterpart: accessibility, scalability, reach, and affordability Schoneveld *et al.* [2018], particularly when paired with VR immersion. These requirements are crucial for a mining company because state-of-the-art procedures involve handling heavy machinery required to accommodate long training periods, complicated logistics, and compromised productivity attributable to work being suspended because of otherwise perfectly serviceable assets.

A workplace can benefit from implementing a serious game because it can increase safety awareness and experience by simulating real work-related scenarios with varying degrees of danger in an environment where failure offers minimal risk Liang *et al.* [2019].

Furthermore, serious games provide opportunities to simplify logistics and reduce costs by eliminating the need to allocate physical assets Creutzfeldt *et al.* [2012]. Compared to traditional methods, serious games improve worker performance and minimize mistakes Creutzfeldt *et al.* [2012]. Another benefit is their ability to cover a wide range of scenarios and events that are difficult to replicate through traditional training methods.

Existing literature on VR-based serious games indicates a low adoption rate in companies Liebrecht *et al.* [2021].

3 Wheel loader virtual inspection serious game

This serious game uses virtual reality to simulate the inspection procedure of wheel loaders, accurately replicating the sequence of checks performed in real-world operations. The system allows operators to pre-configure their session by selecting the machine model and inspection parameters, which can be customized by a supervisor to define specific defects and penalties. During the activity, users navigate freely through the virtual environment, interact with the machine, and complete an inspection checklist using a virtual tablet. At the end of the session, an evaluation system compares the user's responses with an answer key, providing detailed feedback, recording the score, and allowing the process to be repeated with randomized variations. In this section, we further detail the mechanics, challenges and elements of the game that transform the simulator into an engaging training tool, as illustrated by the general flow diagram of the game presented in Figure 2.

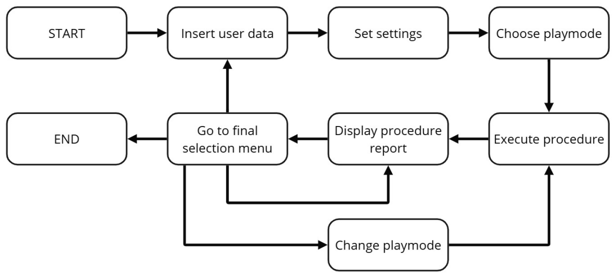

Figure 2. Visual Overview of the Game's Flowchart

3.1 Initial Scene

The initial scene serves as the entry point to the serious game, where users configure their preferences and provide necessary personal information to customize the training experience. This scene includes the following steps:

3.1.1 User Configuration:

Users input personal and configuration information (Figure 3 essential for tailoring the experience to individual needs and tracking performance.

3.2 Parameter Configuration:

Supervisors can set specific parameters for the training session (Figure 4), including serious game mode (evaluative or tutorial), difficulty level, and maximum allowed inspection time. These settings can adjust the simulation for different experience levels and training objectives.

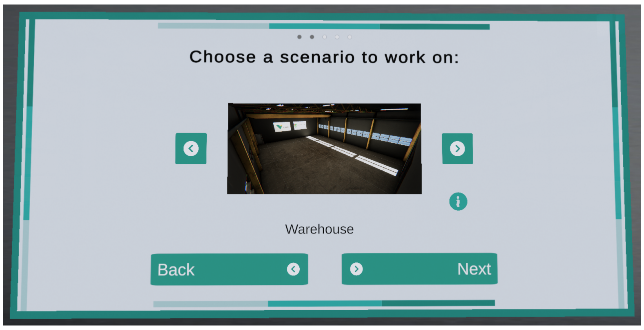

Figure 3. Representation of scenario selection

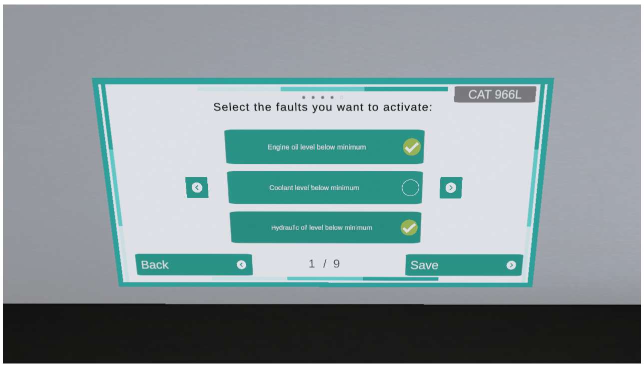

Figure 4. Personalized defect selection interface designed for employee training

3.3 Game Modes

The serious game provides two distinct game modes, each with specific objectives and approaches for training.

3.3.1 Evaluation Mode:

The evaluation mode assesses users' ability to independently identify defects without guidance. Users conduct inspections on their own, relying on their knowledge and skills to locate and identify defects. This mode does not provide real-time feedback, allowing for a more accurate assessment of the competence of the operator. It is ideal for testing the skills of experienced operators and performing formal performance evaluations. In the Figure 5 shows a representation of the procedure in evaluation mode.

Figure 5. Representation of the procedure in evaluation mode

3.3.2 Tutorial Mode:

The tutorial mode guides users through the inspection process, offering real-time feedback and instructions. Users receive detailed guidance on how to locate components and identify defects, with immediate feedback provided to correct errors and guide the user. In the Figure 6 shows a representation of the procedure in tutorial mode. This mode is more suitable for novices or initial training, making it perfect for new operators or those learning to identify specific defects for the first time.

Figure 6. Representation of the procedure in tutorial mode

3.4 Procedure Scene

The virtual machine inspection is conducted in the procedure scene, which is highly interactive and realistically simulates the inspection process. The flow of this scene includes the following steps:

3.4.1 Introduction and Orientation:

Upon entering the procedure scene, users receive a brief orientation about the machine and inspection objectives. This introduction is adjusted based on the selected mode (evaluation or tutorial).

3.4.2 Non-Linear Inspection:

Users can freely navigate the virtual environment and inspect different machine components. The non-linear inspection allows users to choose the order of areas to be checked, promoting a realistic and practical approach.

3.4.3 Component Interaction:

Using VR controllers, users can interact with machine components such as doors, hoods, and moving parts (Figure 7). They can examine each part in detail, identifying deliberately introduced defects to train their identification skills.

3.4.4 Defect Logging:

When a defect is identified, users log their observations through a virtual control panel shown in Figures 5 and 6. This panel simulates real inspection tools, allowing a smooth transition between virtual practice and real-world application.

3.4.5 Real-Time Feedback:

In the tutorial mode, the system provides real-time feedback, guiding users in locating and identifying defects. In the eval-

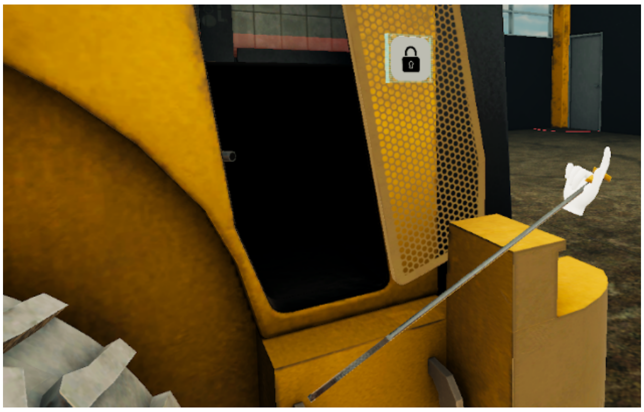

Figure 7. Interaction with the engine dipstick

Figure 8. Representation of the final report

uation mode, users conduct the inspection without assistance, testing their skills independently.

3.5 Review and Evaluation

After completing the inspection, users go through a review and evaluation phase, which includes the following steps:

3.5.1 Inspection Summary:

Users view a summary of their inspection, including time spent, responses provided, and any penalties applied for exceeding the time limit.

3.5.2 Data Storage:

All inspection information is automatically stored in a NoSQL database. This storage enables subsequent analysis by supervisors and the generation of performance reports.

3.5.3 Error Review:

Users have the opportunity to review errors made during the inspection (Figure 8). This review serves as an important learning tool, although it does not permit modifying recorded responses.

3.5.4 Detailed Feedback:

In the tutorial mode, users receive detailed feedback on each error, including tips on how to avoid such errors in the future. In the evaluative mode, the feedback is a summary, encouraging users to reflect on their practices.

3.6 Finalization and Post-Inspection Options

After the review, users can choose from several options to either finalize their session or continue training:

3.6.1 Modify Settings:

Users can return to the initial scene to alter personal settings or supervisor parameters, adapting the next session to their needs.

3.6.2 Switch Game Modes:

The option to switch between evaluative and tutorial modes is available, enabling users to adjust the intensity and focus of the training.

3.6.3 Repeat Session:

Users can opt to repeat the same inspection session to reinforce learning or improve their performance.

3.6.4 Exit Simulator:

Finally, users can choose to exit the game, saving their information and ending the training session.

The game flow is meticulously designed to deliver an effective and personalized training experience, spanning from initial setup to detailed review and repetition options. This modular and interactive design ensures that heavy machinery operators can safely and realistically develop their inspection skills, thereby contributing to continuous improvement in workplace safety and efficiency.

4 System Description

The VR system developed for inspecting wheel loaders aims to provide an immersive and realistic training environment for operators. Its primary objective is to enhance the efficiency and accuracy of pre-operational inspections, enabling operators to identify and evaluate equipment defects effectively.

The development of this software is driven by the necessity to improve the training of heavy machinery operators. The virtual environment offers a safe and controlled platform for performing inspections, eliminating the risks associated with real equipment usage. In addition, VR technology enables the simulation of diverse conditions and defects that would be challenging to replicate consistently in physical settings.

All software and hardware are described as follows. However, the questionnaires used to assess user experience, are described in detail in the Appendices. Again, the text in some figures in the following sections is in Portuguese language. Some employees in the company were trained using this language.

4.1 System Architecture

The VR serious game was developed using Meta Quest 2 for its standalone capability, eliminating the need for an external computer to process the application. The system architecture revolves around three core modules: rendering, interaction, and feedback. In addition, the implementation uses OpenXR, ensuring compatibility with a variety of headsets. The primary advantage of the application lies in its autonomy.

4.1.1 Rendering Module:

The rendering module employs physically based rendering (PBR) techniques to achieve highly realistic graphics (Figure 9). This approach is essential for accurately simulating material properties and lighting conditions, closely mirroring real-world environments.

Figure 9. Example of a highly realistic texture

4.1.2 Interaction Module:

The interaction module extends the user's engagement beyond conventional navigation by enabling direct manipulation of machine components through VR controllers. As detailed in Section 3.4.3, operators can interact with elements such as doors, hoods, and moving parts to examine and identify deliberately embedded defects. This design closely emulates real-world inspection procedures by offering immediate, context-sensitive feedback. In addition, Figure 10 illustrates a raycast representation of the locomotion of the player through teleportation, demonstrating the module's intuitive navigation mechanism that facilitates seamless movement within the virtual environment. Together, these features reinforce the fidelity of the simulation, ensuring that the training experience effectively mirrors the practical challenges of pre-operational inspections.

4.1.3 Feedback Module:

The feedback module provides detailed visual responses to users' actions to enhance usability and immersion (Figure 11). This feedback is essential for guiding operators during training, providing immediate and relevant information about their interactions in the virtual environment.

These modules collectively ensure that the serious game provides a comprehensive, safe, and realistic training experience. They enable heavy machinery operators to identify and

Figure 10. Raycast representation of player locomotion

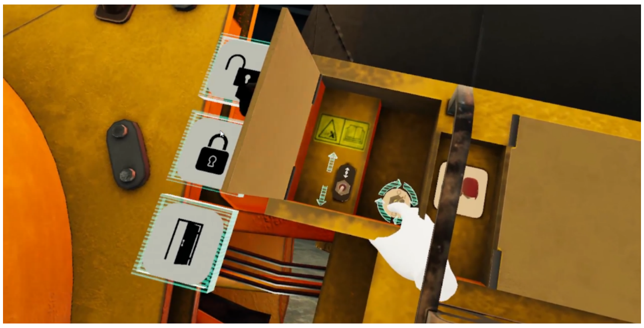

Figure 11. Representation of user interaction with the serious game

evaluate defects with enhanced accuracy, thereby optimizing training effectiveness and operational readiness. .

4.2 Technical Implementation

The serious game was developed using the C# programming language and the Unity platform, chosen for their robustness and flexibility in creating immersive VR experiences. Several additional tools used to create the visual assets are listed next.

4.2.1 3ds Max:

This software was used for 3D modeling various elements within the virtual environment, ranging from heavy machinery to interactive objects.

4.2.2 Substance Painter:

Integral to the process, substance painter enabled the application of complex visual effects to 3D models. This included creating realistic materials and detailed textures, significantly enhancing the visual quality of the game.

4.2.3 Materialize:

Used for fine-tuning object textures, Materialize played a crucial role in creating realistic details and optimizing graphical performance.

Combining these tools allowed for the creation of a highly detailed and realistic virtual environment. This approach ensures an engaging and effective training experience tailored for heavy machinery operators.

5 Material and Methods

5.1 Objectives and Methodology

The idea for this study arose from a need for employee training using software capable of simulating the fault screening environment specific to each machine in a mining company (target study). This software aims to provide comprehensive training for employees responsible for their respective work areas. The project was developed using the minimum viable product approach. Initial iterations were built in Unity, focusing on implementing various machine faults. Subsequent versions were refined based on feedback from participants to correct errors, introduce new functions, and improve the user interface. These iterative updates and improvements have continued to evolve the training environment into its current state.

5.2 Ongoing Training at the Mining Industry

In-house training courses are offered to the workforce across various sectors of the mining industry, emphasizing both theoretical knowledge and practical skill, particularly in the maintenance sector. For VR training to be effective, the industry requires a highly accurate and regularly updated 3D model of the CAT 966L machine, ensuring its closely mirrors real-world conditions and operations.

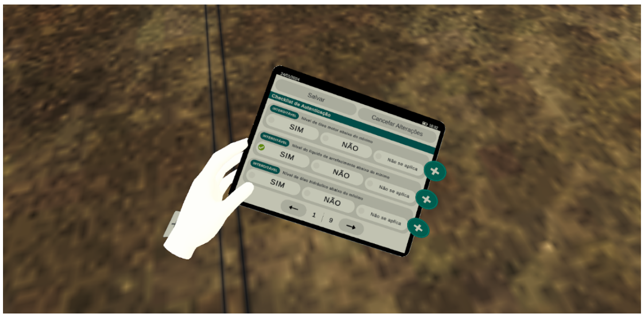

Figure 12. Tablet used for validating the training environment

5.3 Validation with Participants

After numerous tests designed to be as realistic as possible, we validated the training environment using a tablet interface, as shown in Figure 12. Participants filled out a form displayed on a tablet on their left wrist, listing all possible defects (see Figures 5 and 6). The results were saved and made available to the training supervisors for analysis and comparison. This process created a detailed record (Figure 8) of each participant's mistakes and successes. Training supervisors have complete autonomy to enable or disable specific faults, allowing for targeted training tailored to each employee. This capability helps in identifying faults and potential hazards, thereby reducing the likelihood of additional faults and workplace accidents.

5.4 Data Analysis and Feedback

After validation, questionnaires (see Appendices) are administered to assess the effectiveness of the tasks conducted by the team of employees in simulating the working environment as closely as possible. The goal is to minimize errors on the real machine. Various analysis methods are used to determine whether the process was successful and to gauge the stress levels experienced by participants. In addition to the questionnaires provided by the mining company, other methods provide an overview of subjective usability evaluations.

5.5 Supervisors

After collecting the data, supervisors observed a notable improvement in the individual performance of each participant based on the analyzed results. The feedback indicated that the ease of immersion in the software made the training increasingly simple and practical to complete. In addition, suggestions were made to enhance the visual and connective structure of the software, such as updating interfaces and movement controls to be more intuitive and inclusive.

5.6 Workers

Workers were asked about their experience with the training environment and the changes made to the machine compared to the previous model. The feedback is essential for identifying necessary changes and success points. Workers were also asked how the evolution of the training environment influenced their ability to assimilate faults compared to working with the real machine.

5.7 NASA Task Load Index

We observed continuity and reliability in the results obtained at the end of the research and from the results collected using the NASA Task Load Index (TLX) method Hart [1986]. This ensured the quality of the research processes and their favorable outcomes, supporting updates to the 3D model. Data was collected from 16 participants, showing a positive average in most parameters, indicating that the task load is light and enjoyable for employees in this industry. See questionnaire A.2 in section Appendices.

5.8 System Usability Scale

A survey using the system usability scale (SUS) was conducted to determine the cognitive load and time spent on tasks, considering their potential for continuous and partly repetitive execution. This survey validated the usability of the training environment Brooke [1996]. For this data collection, ten direct feedback responses were collected from employees who had undergone training, revealing a high level of acceptance for the training. See questionnaire A.1 in section Appendices.

6 Computational Results

The paper highlights the improvements implemented in the serious game based on feedback collected in a previous survey of company employees and their supervisors, as discussed in the paper by Borges *et al*. [2024]. The areas identified for improvement are compared, and the actions taken to improve them are presented. The NASA TLX (Section 5.7) and SUS (Section 5.8) surveys were conducted to validate these improvements, focusing on the user experience and functionality of the serious game.

6.1 Supervisors' Feedback

Initially, a survey was conducted on the old version of the serious game to understand its effectiveness in identifying operators facing difficulties and to evaluate how much each application increased the operator's knowledge about potential equipment malfunctions.

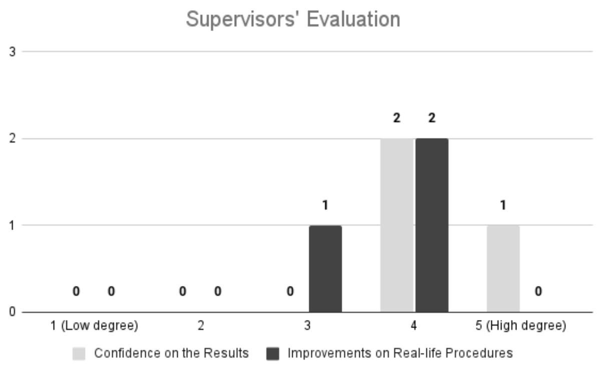

Figure 13. Results of research into the application's potential to assist supervisory functions

The results of the survey are shown in Figure 13. The representation is given on a 5-point Likert scale, with 0 indicating there is "no improvement and no confidence" and 5 indicating "many improvements and high confidence."

After this evaluation, we conducted a qualitative survey with the supervisors to obtain their suggestions for modifications to the model. The primary change they recommended was to the cabin. Consequently, we focused on improving it. Figure 14 illustrates the previous version of the cabin, which is empty except for the seat. Figure 15 depicts the enhancements made to the cabin, including the addition of new objects.

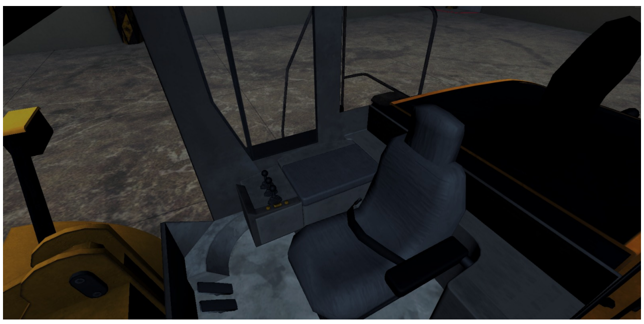

Figure 14. Cabin object in the old version

6.2 Operators' Feedback

After the supervisors' evaluations, we performed the same procedure with operators who were undergoing VR training.

Figure 15. Cabin object in the new serious game version

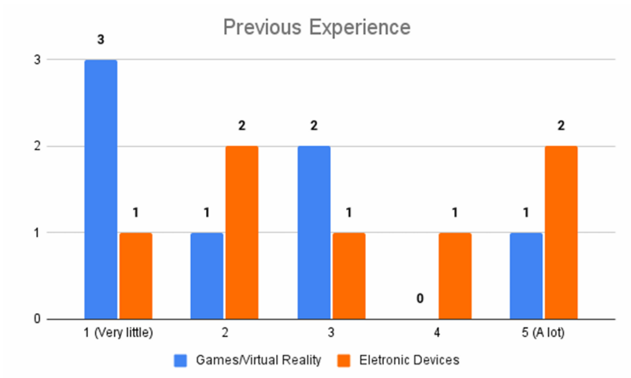

Figure 16. Previous experience with video serious games,VR, and electronic devices

The first question addressed the operators' previous experience with serious games, VR, or electronic devices. Figure 16 shows the results, generated using a 5-point Likert scale, where 5 represents extensive experience and 1 represents minimal experience with video games,VR, and electronic devices.

6.3 NASA Task Load Index Results

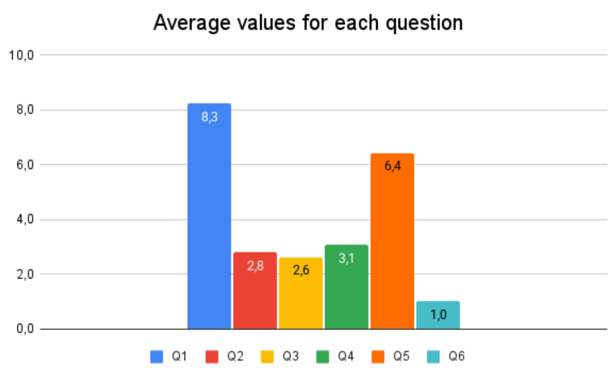

Figure 17. Assessment of the task's mental demand

Figure 17 presents the evaluation results, indicating that training was considerably mentally demanding for the operators. This outcome is expected, as it was their first experience with Virtual Reality (VR) technology. The NASA TLX assessment revealed relatively high effort and mental demand scores, which align with typical first-time VR usage. Despite this initial cognitive load, the overall effectiveness of VR in the evaluated context was supported by other indicators, which remained consistent with expectations. The average NASA TLX score was approximately 45, a value that, while moderate, is reasonable given the operators' lack of prior exposure to the system. Since lower scores indicate reduced cognitive strain, these values are expected to decline over time as familiarity with the system increases, leading to improved usability. To facilitate this adaptation process, the control interface was simplified and movement mechanics refined, with the aim of reducing cognitive load and enhance user experience.

6.4 System Usability Scale Results

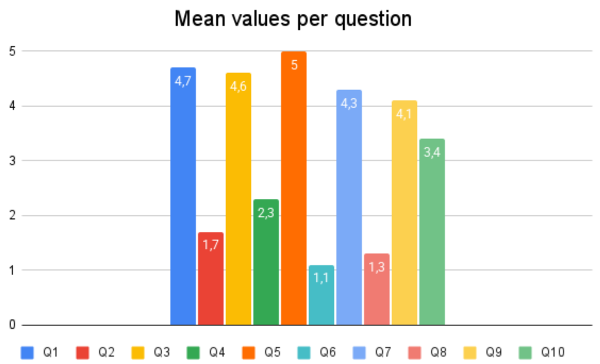

Figure 18. Mean SUS scores per question, illustrating user perceptions of ease of use, navigation, reliability, and overall system usability

The SUS results demonstrate that the VR simulator is both easy to use and effective. As shown in Figure 18, which presents the mean score for each question, users rated the system highly in terms of ease of use, clear navigation, and overall reliability, indicating that its features are well integrated. Although initial interactions required additional focus, users adapted quickly to the interface. A SUS score of 82.25 supports the conclusion that the system is intuitive and efficient. Further, responses to Questionnaire A.4 showed that participants experienced no health issues or cybersickness, with an average score of 4.86 out of 5 on key usability questions. These outcomes are consistent with the NASA TLX and SUS findings, confirming that the VR simulator delivers a user-friendly and efficient experience.

6.5 Qualitative Evaluation

Figure 19. Representation of cabin access

In addition to the quantitative evaluation, we performed a qualitative evaluation to obtain recommendations for changes to the serious game. One of the most requested changes was to enable the operator to climb onto the machine. In response, we updated the serious game to allow not only climbing onto the machine but also turning it on. Figure 19 shows the result of these changes to the climbing mechanics.

Another recommendation was to increase the number of items for inspection, which we incorporated into the new system update.

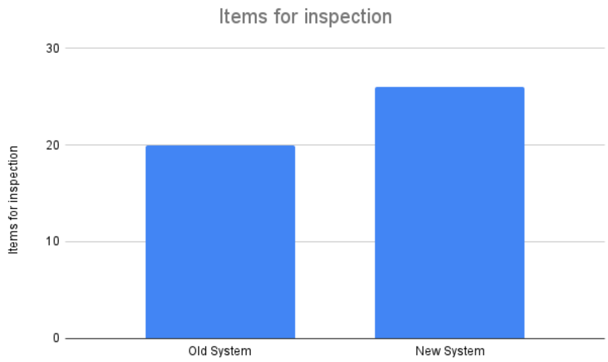

Figure 20. Items for inspection

The previous version of the serious game included 20 inspection items. After the update, six new items were added, bringing the total to 26 items, representing a 30% increase, as illustrated in Figure 20.

In the previous study, the serious game used in the mining industry showed a positive impact on operator training and instruction. However, the majority of operators were not familiar with VR devices, and supervisors highlighted the need for improvements, especially in matching the procedures and graphics of the serious game to real-world conditions.

To address these concerns, the fidelity of the serious game was increased to better reflect the real environment. This involved improving the graphics, quality, and texture of the objects, as well as for improving the interface and user experience. Subsequent evaluations of the new version indicate that these improvements have proven effective.

6.6 Project costs

Costs associated with hardware and software were calculated based on the exchange rate on May 15, 2024 (1 USD = 5.01 BRL). These costs were considered in the outsourced contracts for supervising and training a group of up to 12 employees. The training plan comprised 30 h of combined theoretical and practical applications. Based on average market rates, the total cost for these services was calculated to be 3,300.91 USD.

Initially, the model utilized the HTC Vive VR headset, requiring an accompanying computer. However, the new model used the Oculus Quest 2, which could run the application autonomously. The total estimated budget for implementing the VR serious game is detailed in Table 1.

The initial phase includes 300 h of software development work per student, costing 1.46 USD per hour, involving a team of six students (Team Expenses). In addition, 6 h of instructional time are considered at a cost of 10.00 USD per hour, for a team of 12 volunteer workers (Instructor).

Table 1. Simulator costs

Item	Cost [US$]
XPS 8960	2,026.94
Dell Monitor E1616H	105.98
Wireless mouse and keyboard	40.16
Oculus Quest 2	374.65
Team spending	2,628.00
New deployments	2,722.50
Maintenance	425.48
Total	**8,373.71**

An annual interest rate of 10% was applied to new deployments to update the serious game with team. Subsequently, annual maintenance costs were included, resulting in a total calculated cost 8,373.71 USD for developing and maintaining the serious game.

7 Discussion

Several points can be highlights of participants about serious game as follows: after noticing that certain professional operators had limited knowledge of video games, virtual reality, and electronic devices. However, these operators were able to interact with the game and complete all instructions; another issue suggested to change was that the operators can climb onto the machine; another suggestion included increasing the number of items for inspection, which we included in the future game. We also highlight that the developed game obtained at a relatively low cost considering the hardware and software involved in the serious game.

We emphasize that the participation of professional operators has principles voluntary, anonymous, and confidentiality for collecting of computational results. Moreover, personal information was not collected in none research step. Thus, the ethical considerations in this research reached a set of principles guided in the research designs and practices. Furthermore, mining company installations in certain sectors are already using screen exposure from virtual reality goggles. Thus, the eyesight of operators (participants in this research) when they are using the developed serious games and answering the questionnaire is bit affected by this operation.

Moreover, although the questionnaires use questions to participants, there was no direct or indirect handling of personal data or personal information. There is not a collection of participants about gender, address, salary range, and so on. In this sense, our work is in accordance with Resolution number 510, April 7, 2016, that treat about research ethics in the Brazilian CEP/CONEP system, which in the first Article, in its sole paragraph and item I: the following will not be recorded or evaluated by the system, public opinion surveys with unidentified participants.

Despite the fact that all operators in the sector participated in the data collection, the research limitations can be considered about number of participants. Moreover, in the future the research could collect data in several times. Thus, we suggested as future investigation to consider these challenges.

In this sense, there are other challenges that can be considered: (1) the development of additional scenarios to cover a wider range of operational conditions. Consequently, it is providing more comprehensive training for operators; (2) the usability improvements through of feedback of operators and conduct further operator studies to refine the user interface. Therefore, all operators, regardless of their technological proficiency, will be able to use the serious game in a user-friendly way thanks to this; (3) finally, the conduct longitudinal studies on training impact in long-term with user participation to enhance data collection. Moreover, assess the long-term impact of training and inspection using the serious game on performance of the operators and safety in real-world operations. These studies are expected to yield valuable insights into the effectiveness of training and inspection and over time.

The following specifications and components are provided to guarantee the reproducibility of the serious game environment. The environment was developed and rendered using Unity version 2021.3.5f1, which is the system's build platform. Version 4.4.1 of XR Plugin Management and XR Interaction Toolkit version 2.0.4, which manage compatibility with various VR devices respectively, are software components. This allows for user interaction, including object manipulation, within the VR space. Also, the Oculus Hand Models available at the Oculus Developer Center are utilized to depict hands in the virtual environment. The serious game can be replicated effectively by others by adhering to these versions and configurations.

By dealing with the points, challenges, and specifications mentioned earlier, the developed serious game for inspection and training can continue in its evolution. In this sense, it is providing even greater value to the industry in a broader way and other sectors that rely on heavy machinery. This corroborates in the safe training, low cost, interactively, modular, user-friendly interface, reproducibility, updated system, and so on.

8 Conclusion and future work

The findings of this study revealed that the VR-based serious game allowed participants to acquire technical skills necessary for operating a real wheel loader. The developed VR serious game integrated game elements into the simulation to engage users effectively. Therefore, inspection procedures aimed at identifying machine defects became easier to handle. This result justifies the significance of such technology in simplifying training process, reducing the risk of accidents and errors, and enhancing overall safety.

The VR-based serious game represents a tangible application of Industry 4.0 technology, favoring industrial machinery inspection and training across various industrial sectors. The primary goal of Industry 4.0 is to enhance and increase the efficiency and productivity of operations, develop new services, and enhance products. In this sense, this serious game collaborates with Industry 4.0.

The VR serious game is proposed as a training tool to prepare company staff for inspecting and operating a wheel loader. Implementing such a game for inspection and training purposes can streamline the training process, reduce costs, and enhance the safety of company personnel.

According to a survey answered by professional collaborators, limitations of the serious game were identified, including issues with internal motor mechanisms, interactions within the cabin interior, and variations in elements with defects. Future developments of the serious game aim to address these limitations and introduce additional functionalities, These enhancements will include sound and movement-based inspection features, such as testing horns, engines, and reversing alarm sounds, along with functional windshield wipers.

The serious game can be expanded to include various technical procedures, such as a maintenance procedure for a tamping machine. In this scenario, players interact with tools and perform procedures following meticulous planning. While creating these new procedures demands significant effort, the game's structure was designed from the ground up with such expansions in mind. Furthermore, the proposed serious game aims to be a robust application encompassing different machines, procedures, and scenarios to serve as an effective training tool for maintenance professionals.

In addition, as a suggestion for future work, the serious game can be used as application to offer recognition to collaborators of the mining company, such as titles, in a gamification strategy. In addition, the company can provide incentives such as bonuses, opportunities for advancement within the company, motivate employees to engage in great excitement, and establish objectives for collaborators to accomplish. All these incentives to be will include in gamification strategies.

Despite the game's realistic rendering capabilities, it cannot fully replace hands-on training with a real wheel loader. Limitations of this work are attributed to the inherent nature of VR platforms, virtual environments, and the challenge of displaying multi-modal stimuli. The developed serious game in this work, in a virtual-reality goggle environment, can to be adapted in a format in computer screens for people with difficulties these virtual environments.

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Declarations

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Authors' Contributions

All authors contributed to the conception and investigation of this work. LFMRB, ASM, JVLF, TPL, ADAN, and MGN performed the experiments, data curation, and carried out the formal analysis. RVA, MQS, and MM established the methodological bases and the validation of paper. LFMRB, ASM, JVLF, TPL, ADAN, and MGN wrote the original draft work and developed the software. RVA has been responsible for project administration. RVA, MQS, and MM obtained the funding acquisition and the resources. MM was a supervisor of the research project. All authors worked on reviewing, editing and approved the final paper.

Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Akpan, I. J. and Offodile, O. F. (2024). The role of virtual reality simulation in manufacturing in industry 4.0. *Systems*, 12(1). DOI: https://doi.org/10.3390/systems12010026.

Alaloul, W. S., Saad, S., and Qureshi, A. H. (2022). *Construction Sector: IR 4.0 Applications*, pages 1341–1390. Springer International Publishing, Cham. DOI: https://doi.org/10.1007/978-3-030-84205-5_36.

Ali, S. G., Wang, X., Li, P., Jung, Y., Bi, L., Kim, J., Chen, Y., Feng, D. D., Magnenat Thalmann, N., Wang, J., and Sheng, B. (2023). A systematic review: Virtual-reality-based techniques for human exercises and health improvement. *Frontiers in Public Health*, 11. DOI: https://doi.org/10.3389/fpubh.2023.1143947.

Borges, L. F. M. R., Viana, P. H. P., de Oliveira, T. a. R., Martins, T. d. S., Andreão, R. V. a., Schimidt, M., and Mestria, M. (2024). Evaluating virtual reality simulations for wheel loader inspection. In *Proceedings of the 25th Symposium on Virtual and Augmented Reality*, SVR '23, page 8–16, New York, NY, USA. Association for Computing Machinery. DOI: https://doi.org/10.1145/3625008.3625010.

Brooke, J. (1996). Sus: A quick and dirty usability scale. In Jordan, P. W., Thomas, B., Weerdmeester, B. A., and McClelland, I. L., editors, *Usability Evaluation in Industry*, pages 189–194. Taylor and Francis, London.

Commission, E. (2018). *Re-finding industry – Defining innovation*. European Commission and Directorate-General for Research and Innovation - Publications Office. DOI: https://data.europa.eu/doi/10.2777/927953.

Corso, A. D., Stets, J. D., Luongo, A., Nielsen, J. B., Frisvad, J. R., and Aanæs, H. (2017). Virtual reality inspection and painting with measured brdfs. In *SIGGRAPH Asia 2017 VR Showcase*, SA '17, New York, NY, USA. Association for Computing Machinery. DOI: https://doi.org/10.1145/3139468.3139472.

Creutzfeldt, J., Hedman, L., and Felländer-Tsai, L. (2012). Effects of pre-training using serious game technology on cpr performance—an exploratory quasi-experimental transfer study. *Scandinavian journal of trauma, re-*

suscitation and emergency medicine, 20(79):79. DOI: https://doi.org/10.1186/1757-7241-20-79.

Dadhich, S. (2018). *Automation of Wheel-Loaders*. PhD thesis, Lulea University of Technology, Embedded Internet Systems Lab.

Eschen, H., Kötter, T., Rodeck, R., Harnisch, M., and Schüppstuhl, T. (2018). Augmented and virtual reality for inspection and maintenance processes in the aviation industry. *Procedia Manufacturing*, 19:156–163. Proceedings of the 6th International Conference in Through-life Engineering Services, University of Bremen, 7th and 8th November 2017. DOI: https://doi.org/10.1016/j.promfg.2018.01.022.

Guo, Z., Zhou, D., Zhou, Q., Zhang, X., Geng, J., Zeng, S., Lv, C., and Hao, A. (2020). Applications of virtual reality in maintenance during the industrial product lifecycle: A systematic review. *Journal of Manufacturing Systems*, 56:525–538. DOI: https://doi.org/10.1016/j.jmsy.2020.07.007.

Hart, S. G. (1986). NASA task load index (TLX). In *NASA Ames Research Center Moffett Field, CA United States*, pages 1–26.

Hess, T. and Gunter, G. (2011). Comparison of learning experiences and outcomes between a serious game-based and non-game-based online american history course. In Barton, S.-M., Hedberg, J., and Suzuki, K., editors, *Proceedings of Global Learn 2011*, pages 1223–1228, Melbourne, Australia. Association for the Advancement of Computing in Education (AACE).

Javaid, M., Haleem, A., Singh, R. P., Suman, R., and Gonzalez, E. S. (2022). Understanding the adoption of industry 4.0 technologies in improving environmental sustainability. *Sustainable Operations and Computers*, 3:203–217. DOI: https://doi.org/10.1016/j.susoc.2022.01.008.

Joshi, S., Hamilton, M., Warren, R., Faucett, D., Tian, W., Wang, Y., and Ma, J. (2021). Implementing virtual reality technology for safety training in the precast/ prestressed concrete industry. *Applied Ergonomics*, 90:103286. DOI: https://doi.org/10.1016/j.apergo.2020.103286.

Korkut, E. H. and Surer, E. (2023). Visualization in virtual reality: a systematic review. *Virtual Reality*, 27:1447–1480. DOI: https://doi.org/10.1007/s10055-023-00753-8.

Liang, Z., Zhou, K., and Gao, K. (2019). Development of virtual reality serious game for underground rock-related hazards safety training. *IEEE Access*, 7:118639–118649. DOI: https://doi.org/10.1109/ACCESS.2019.2934990.

Liebrecht, C., Kandler, M., Lang, M., Schaumann, S., Stricker, N., Wuest, T., and Lanza, G. (2021). Decision support for the implementation of industry 4.0 methods: Toolbox, assessment and implementation sequences for industry 4.0. *Journal of Manufacturing Systems*, 58:412–430. DOI: https://doi.org/10.1016/j.jmsy.2020.12.008.

Luz Melo, R., Moreira, V. d. S., Amaral, E. M. H. d., and Domingues Júnior, J. S. (2025). Victus exergame: An approach to rehabilitation of amputees based in serious game. *Journal on Interactive Systems*, 16(1):137–147. DOI: https://doi.org/10.5753/jis.2025.4194.

Malpartida, K. F. C. and Rodrigues, K. R. d. H. (2025). Building serious games to exercise computational thinking: Initial evaluation with teachers of children on the autism spectrum. *Journal on Interactive Systems*, 16(1):148–162. DOI: https://doi.org/10.5753/jis.2025.4492.

Mitgutsch, K. and Alvarado, N. (2012). Purposeful by design? a serious game design assessment framework. In *Proceedings of the International Conference on the Foundations of Digital Games*, FDG '12, page 121–128, New York, NY, USA. Association for Computing Machinery. DOI: https://doi.org/10.1145/2282338.2282364.

Nguyen, A., Wüest, P., and Kunz, A. (2020). Human following behavior in virtual reality. In *Proceedings of the 26th ACM Symposium on Virtual Reality Software and Technology*, VRST '20, New York, NY, USA. Association for Computing Machinery. DOI: https://doi.org/10.1145/3385956.3422099.

Pilote, B. and Chiniara, G. (2019). Chapter 2 - the many faces of simulation. In Chiniara, G., editor, *Clinical Simulation (Second Edition)*, pages 17–32. Academic Press, second edition edition. DOI: https://doi.org/10.1016/B978-0-12-815657-5.00002-4.

Radianti, J., Majchrzak, T. A., Fromm, J., and Wohlgenannt, I. (2020). A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda. *Comput. Educ.*, 147:103778. DOI: https://doi.org/10.1016/j.compedu.2019.103778.

Rahman, O. F., Kunze, K. N., Yao, K., Kwiecien, S. Y., Ranawat, A. S., Banffy, M. B., Kelly, B. T., and Galano, G. J. (2024). Hip arthroscopy simulator training with immersive virtual reality has similar effectiveness to nonimmersive virtual reality. *Arthroscopy: The Journal of Arthroscopic & Related Surgery*. DOI: https://doi.org/10.1016/j.arthro.2024.02.042.

Ribeiro de Oliveira, T., Biancardi Rodrigues, B., Moura da Silva, M., Antonio N. Spinassé, R., Giesen Ludke, G., Ruy Soares Gaudio, M., Iglesias Rocha Gomes, G., Guio Cotini, L., da Silva Vargens, D., Queiroz Schimidt, M., Varejão Andreão, R., and Mestria, M. (2023). Virtual reality solutions employing artificial intelligence methods: A systematic literature review. *ACM Comput. Surv.*, 55(10). DOI: https://doi.org/10.1145/3565020.

Ribeiro de Oliveira, T., Martinelli, T. F., Bello, B. P., Batista, J. D., Silva, M. M. d., Rodrigues, B. B., Spinassé, R. A. N., Andreão, R. V., Mestria, M., and Schimidt, M. Q. (2020). Virtual reality system for industrial motor maintenance training. In *2020 22nd Symposium on Virtual and Augmented Reality (SVR)*, pages 119–128. DOI: https://doi.org/10.1109/SVR51698.2020.00031.

Romero-Gázquez, J. L., Cañavate-Cruzado, G., and Bueno-Delgado, M.-V. (2022). In4wood: A successful european training action of industry 4.0 for academia and business. *IEEE Transactions on Education*, 65(2):200–209. DOI: https://doi.org/10.1109/TE.2021.3111696.

Rufino Júnior, R., Classe, T. M. d., Santos, R. P. d., and Siqueira, S. W. M. (2023). Current risk situation training in industry, and games as a strategy for playful, engaging and motivating training. *Journal on Interactive Systems*, 14(1):138–156. DOI: https://doi.org/10.5753/jis.2023.3222.

Sancho-Esper, F., Ostrovskaya, L., Rodriguez-Sanchez, C., and Campayo-Sanchez, F. (2023). Virtual reality in retirement communities: Technology acceptance and tourist destination recommendation. *Journal of Vacation Marketing*, 29(2):275–290. DOI: https://doi.org/10.1177/13567667221080567.

Schoneveld, E., Lichtwarck-Aschoff, A., and Granic, I. (2018). Preventing childhood anxiety disorders: Is an applied game as effective as a cognitive behavioral therapy-based program? *Prevention Science*, 19(2):220–232. DOI: https://doi.org/10.1007/s11121-017-0843-8.

Shao-Chen Chang, Ting-Chia Hsu, Y.-N. C. and yung Jong, M. S. (2020). The effects of spherical video-based virtual reality implementation on students' natural science learning effectiveness. *Interactive Learning Environments*, 28(7):915–929. DOI: https://doi.org/10.1080/10494820.2018.1548490.

Sinnott, C., Liu, J., Matera, C., Halow, S., Jones, A., Moroz, M., Mulligan, J., Crognale, M., Folmer, E., and MacNeilage, P. (2019). Underwater virtual reality system for neutral buoyancy training: Development and evaluation. In *Proceedings of the 25th ACM Symposium on Virtual Reality Software and Technology*, VRST '19, New York, NY, USA. Association for Computing Machinery. DOI: https://doi.org/10.1145/3359996.3364272.

Soori, M., Arezoo, B., and Dastres, R. (2024). Virtual manufacturing in industry 4.0: A review. *Data Science and Management*, 7(1):47–63. DOI: https://doi.org/10.1016/j.dsm.2023.10.006.

Tsai, W.-L., Chung, M.-F., Pan, T.-Y., and Hu, M.-C. (2017). Train in virtual court: Basketball tactic training via virtual reality. In *Proceedings of the 2017 ACM Workshop on Multimedia-Based Educational and Knowledge Technologies for Personalized and Social Online Training*, MultiEdTech '17, page 3–10, New York, NY, USA. Association for Computing Machinery. DOI: https://doi.org/10.1145/3132390.3132394.

Wang, X. and Wang, X. (2018). Virtual reality training system for surgical anatomy. In *Proceedings of the 2018 International Conference on Artificial Intelligence and Virtual Reality*, AIVR 2018, page 30–34, New York, NY, USA. Association for Computing Machinery. DOI: https://doi.org/10.1145/3293663.3293670.

Zhu, W., Fan, X., and Zhang, Y. (2019). Applications and research trends of digital human models in the manufacturing industry. *Virtual Reality & Intelligent Hardware*, 1(6):558–579. DOI: https://doi.org/10.1016/j.vrih.2019.09.005.

Štaffenová, N. and Kucharčíková, A. (2024). Human capital management – values, competencies, and motivation – concerning industry 4.0. *Economic Research-Ekonomska Istraživanja*, 37(1):2324160. DOI: https://doi.org/10.1080/1331677X.2024.2324160.

Appendices

A Questionnaires

Four questionnaires were used in this research, each consisting a set of questions designed to gather information from professional collaborators. The questionnaires consist of a mix of closed-ended and open-ended questions. We used the system term instead serious game to facilitate the understanding and the answers of professional participants when the participants anwsered the questions about SUS.

A.1 System Usability Scale (SUS)

1. I think I would like to use this system frequently.
2. I find the system unnecessarily complex.
3. I found the system easy to use.
4. I think I would need help from a person with technical knowledge to use the system.
5. I think the various functions of the system are very well integrated.
6. I think the system is very inconsistent.
7. I imagine that people will learn how to use this system very quickly.
8. I found the system difficult to use.
9. I felt confident using the system.
10. I had to learn a lot of new things before I could use the system.

A.2 NASA Task Load Index (TLX)

1. How mentally demanding was the task?
2. How physically demanding was the task?
3. How rushed or fast-paced was the task?
4. How successful were you in meeting the objectives of the task?
5. How hard did you have to work to achieve your level of performance?
6. How insecure, discouraged, irritated, stressed, and annoyed versus secure, satisfied, content, relaxed, and complacent did you feel during the task?

A.3 Supervisors' Questionnaire

1. On a scale of 0–5, how confident are you in the results obtained by the employees during the inspection?
2. On a scale of 0–5, to what extent does the serious game help identify employees who have the most difficulty in carrying out the inspection of the real machine?
3. On a scale of 0–5, to what extent does the serious game help identify flaws in the real machine inspection process that need to be addressed in the future?
4. On a scale of 0–5, did you notice an overall improvement in fault detection on the real machine after using the serious game?
5. Is there anything you would change about the serious game?

A.4 Employees' Questionnaire

1. How old are you?
2. What is your level of education?

3. Do you have any physical health conditions that could be affected by using VR technology (e.g., heart problems, labyrinthitis, epilepsy, eye diseases)?
4. On a scale of 0–5, what is your level of physical well-being today?
5. On a scale of 0–5, what is your previous experience with games or VR experiences?
6. On a scale of 0–5, how familiar are you with using electronic devices such as smartphones, computers, and tablets?
7. On a scale of 0–5, what is your assessment of the level of realism of the VR serious game compared to the real machine?
8. On a scale of 0–5, to what extent has the serious game contributed to strengthening your knowledge of machine inspection?
9. On a scale of 0–5, how practical and immersive did you find the serious game during use?
10. On a scale of 0–5, to what extent did the serious game help increase your attention to detail when observing the real machine?
11. Is there anything you would change about the serious game?