# Virtual Reality For Training:
# A Computer Assembly Application

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***Abstract*— Virtual reality applications aimed at worker training to train professionals are more common with the virtual reality advancements observed in this day and age. More companies search for ways to improve the efficiency and efficacy of their training programs, whilst also reducing training costs. There are several training applications found in the literature, but not many focus on the theme of computer assembly, and only a few have options like an observer's menu or a scoring system. With that in mind, a training application for assembling computer towers was designed. This article will focus on the application's functionalities, the results of questionnaires made to evaluate its quality and usability and potential future work. The study realized had good results and a good, varied sample of volunteers, with a score of 93.4% in the custom-made questionnaire, a cybersickness (SSQ) score of 26.53%, a usability score (SUS) of 90% and a satisfaction (ASQ) score of 17.67%, being that a higher score is better in custom made and SUS questionnaires, and a lower score is better in the SSQ and ASQ questionnaires. Although this project is just a proof of concept, it focuses on a theme that will certainly be explored soon, with the rise of demand for training applications, the ever-growing "gamer" market, and workstations for the design of virtual reality applications, like the one described on this paper.**

***Keywords*— *virtual reality, training application, usability evaluation.***

## I. Introduction

Currently, virtual reality (VR) has reached a point where the general public can access head-mounted displays (HMD) at low-cost, and without compromising the quality of these devices [8]. The number of available VR applications (app(s)) has also spiked dramatically, like in the game industry [6][7], professional sector, like virtual meetings, or the app type that shall be discussed in this document, virtual training apps. This type of application is proving important and useful in a wide range of businesses, due to the cost reduction in worker training, because the need to stop production lines ceases to exist, the HMDs and computers necessary for this training are much cheaper than halting production lines every time training must occur. This solution also helps reduce training time, component waste, and work accidents [1][9].

As a project to develop a solution directed at the computer assembly market, where not many solutions of this type exist, a prototype was developed. With it, new employees in need of training, beginners in the area that may want to assemble their computers or even just learn how to, may learn the components of a desktop computer and the basis of how to assemble one.

## II. State of Art

VR training apps exist in variety in the market, although for this particular situation, not many were observed, so a wider search was conducted to find items that may prove useful in this situation.

The German-Spanish company Siemens-Gamessa [2], chose to improve the training efficiency of its collaborators in specialized, high-cost facilities of wind power generation, by attempting a VR solution (Fig. 1). The app serves to provide training in procedures and help in environmental habituation. It allows several users at the same time, with no time limits and permitting user blunder, but, at the same time, helps with visual assistance to help correct said flaws.

Fig. 1. Several training situations in the Siemens-Gamessa App (adapted from Radhakrishnan et al. [2])

An app designed by Opel, Virtual Assembly Line Training [3] is a customized car assembly line simulator (Fig. 2). This app helps to reduce up to 50% of the critical errors in training and assembly costs, and 40% reduction in



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operator training time. It also permits customization of the cars in the line, different workstations, and alteration of other details. Each operator has custom content tailored for their post. This app is not exclusive to VR, as it is compatible with a mouse and keyboard or an Xbox Kinect.

Fig. 2. An example of usage of the Virtual Assembly Line Training App (adapted from [3])

PC Builder Hero [4] is a VR computer building experience where a user (one at a time) can assemble a computer from start to finish (Fig. 3), and at the end know the price of the current build of the computer. Whilst being minimalistic, it demonstrates the basic steps in computer assembly, component cost and even proper component handling, as static charge can harm electronic devices. This application is intended for personal use, to teach the inner workings of said computer without the danger of costly mistakes. Although this application is a prototype, it presents very similar features to the ones designed for large enterprises.

Fig. 3. At the right we can see the parts available to assemble the computer, along with their prices, at the left we can observe the computer being assembled and the current cost of the build in PC Builder Hero (adapted from Slovikosky et al. [4])

A company by the name of The Irregular Corporation [13], developed an app by the name of PC Builder Simulator, mostly as a game and not for training, that allows the user to run a computer shop where you assemble and repair computers, or it is possible to create computers using every component available in the game. It allows for several different component configurations, as well as software tinkering and even goes as far as having malfunction troubleshooting. However, this application is mostly for personal use and does not currently support virtual reality.

Fig. 4. View of a test bench in Pc Builder Simulator (adapted from [13])

This application presented in fig. 5 (adapted from He et al. [6]) belonging to the industry of construction equipment, is not associated with any company, nor does it have a name. The necessity to increment production rate and quality, and reduce training time and component waste, this VR solution proves beneficial in a sector that is slowly switching over to more precise, digital equipment. A study conducted to test this application gave it a very favourable result.

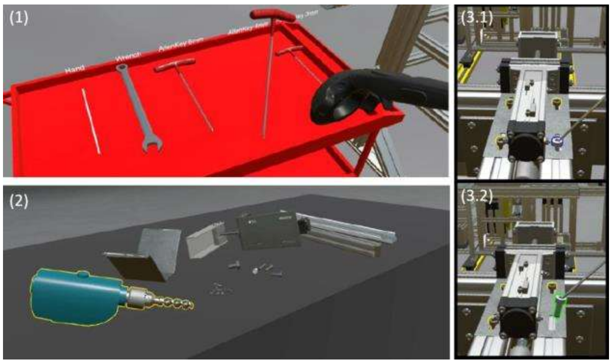


Fig. 5. In (1) we can observe several types of available tools in the VR environment, in (2) a set of parts before assembly, and at (3.1) and (3.2) we can see visual cues that help identify the next steps of the user (adapted from Barkokevas et al. [5])

These apps may be associated with different areas of expertise, but they all share the training theme. However, there are many details that differentiate them function wise. All of them except for PC Building Simulator function in VR, have a wide array of available interactions, and have visual cues to assist in the procedures. Every app presents faithful simulations, help reduce procedural errors, reduce training time, diminish work accidents and component squander. In the case of the Siemens-Gamessa app and PC Builder Simulator, it allows for user error and helps correct those errors. PC Builder Simulator and Virtual Assembly Line Training allow for scenario customization. However, none of these apps present a timer function, none of them have a scoring system able to accurately measure the trainee's performance, and Construction Equipment Assembly Training has its immersion affected by utilizing controllers instead of virtual hands in its simulation.

## III. Application Development

With the goal of creating a software capable of helping reduce employee formation times, product waste reduction, and at the same time, contributing to an enrichment in the formation techniques, and dwelling in an ever-growing theme that is gaming computers and the companies that assemble these.

To be able to create an immersive app, a VR approach was used, where, in a training scenario, similar to a computer shop, the user can experience the same steps of assembly as they would be in the real world, with the addition of visual cues to help the user better understand what he has to do, and a simple scoring system, to promote better performance of the user after a few tries. As a component not necessarily important in an app of this type, but to instigate a better feeling of presence of the user in the scenario, outside stimuli like wind and heat were used.

The heat and wind components were generated with an Arduino, with a circuit created to connect the fan and infrared light bulb, and a simple code set to run them, with a serial output directly from Unity.

## IV. Requirement Analysis

The prototype so far only allows the training to be achieved in a sequential manner, with every component present but only used when the application calls for it. The requirements that were set for a successful app were:

- The app must have a realistic representation of the work environment;
- The app must cover all steps of the computer assembly;
- The app's assembly steps must be accurate and similar to reality;
- The app must have an observer point-of-view (POV), where an outsider may observe, guide, or grade a worker's performance;
- The app must have a scoring system;
- The app must record the worker's score;
- The app must have a timer;
- The app must record the worker's completion time;
- The app must allow teleportation movement.

The non-functional requirements are:

- The app must have interactions easy to understand;
- The app must have interactions easy to use;
- The app must have accurate interactions to when compared to reality;
- The app must be developed in Unity (VR);
- The app must be developed for the Oculus Quest/ Quest 2 system.

Although other head-mounted displays may function correctly with the app, it was developed and tested with the Quest (1 and 2), connected to a computer.

## V. Design and Implementation

A prototype was developed based on the Oculus system, more specifically, the Oculus Quest (1 and 2) HMD, connected to a computer via Oculus Link.

Fig. 6. A complete view of the scenario developed.

In Fig. 6 we can observe a complete view of the training scenario, with an "ideal" look of what the inside of a computer store's workshop would look like to the developer. The spotlights in the scenario are a way to direct light to the computer being assembled, to have a well-illuminated workspace.

Fig. 7. A component of the computer is highlighted, as well as its destination. The components are also accompanied by their names.

In Fig. 7 we can observe some of the parts of the computer, where the object to be picked up and its destination are highlighted, and the components are named. This happens in sequence in all the parts and actions of the computer and serves to help guide what he is meant to do next.

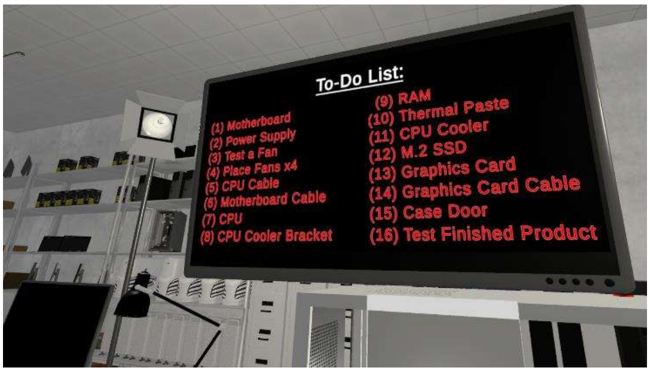


Fig. 8. A monitor displaying the computer's assembly steps.

In Fig. 6, as well as in Fig. 8, there is also a monitor that attempts to guide the user in what part he must assemble next. Step 3 is where the user will test the function of a fan, and after pressing the button he will feel a gust of wind, as he would in a real-world scenario. In step 16 the user clicks the computer's power button, causing it to "spin" 180º and, with the fan turned against the user, spew a few seconds of warm air, produced in the real-world, and felt in the virtual one. After this, the computer finishes "booting up" and the user's score is displayed (Fig. 9).


Fig. 9. A completed computer and the user's score.

Fig. 10 shows the observer's point of view, and if the computer has a second screen, a dedicated HMD POV is displayed there. It has options for four different camera positions and a first-person option for cases where there is no second screen to observe the player's POV.


Fig. 10. Observer's Menu, with different Points of view, time, and player position.

The existing scoring system is quite simple with three possible evaluations depending on assembly time. Under two minutes is "Good", from two to ten minutes it is "Average" and over ten minutes it constitutes "Slow". This scoring was created subjectively and is merely indicative, but still, attempts to inspire the user to do better.

The interactions are basic, to simplify the user's experience, basically revolving around grab and drop operations (Fig. 11). A teleportation system is fully functional, and the action area is limited to the blue patch (Fig. 6) in the ground. There is also a free movement option, where the user can move around with the analogic input of the left remote but needs to be activated with a button in the right hand, as it is cybersickness-inducing for most users.

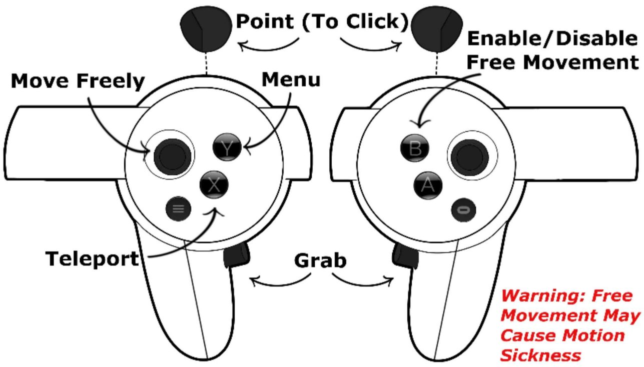


Fig. 11. Oculus Quest 2 Controller Scheme for the prototype (created by the authors).

## VI. Application Evaluation

### A. Sample

To evaluate the usability and quality of the prototype, a between-subjects study was conducted with the participation of 23 volunteers from different age groups (14 to 53 years old, with an average age of 30 years old) and different work areas and education paths, with fourteen participants having at least an academic licensure, two high school students, six people with completed high school, and one volunteer with only middle school level of education. Eleven of these volunteers had an academic licensure in Informatics Engineering, two of which are already employed. The study sample had twelve students, ten employed individuals and one unemployed person, meaning the study used a diverse and disperse sample of volunteers.

### B. Materials

The experiment was conducted using an Oculus Quest 2 HMD, a custom-made Fan, Infrared Bulb, Arduino controlled stimuli system, and a laptop computer with 16GB of ram, a i7-10750h CPU, and a 3080m GPU. The app ran from the computer into the Quest 2 Headset via cable connection using the Oculus Link functionality.

TABLE I. QUESTIONNAIRE EXPERIMENT RESULTS.

| Variables | Minimum[b] | Average | Maximum[b] | % Obtained |
|---|---|---|---|---|
| **Age** | 14 | 30 | 53 | |
| **Experience With Computers** | None (1) | Intermediate (3.26) | Good (4) | 81.5% |
| **Experience With VR** | None (1) | Basic (1.96) | Good (4) | 49% |
| **Time/Score** | 2 minutes & 43 seconds (Score: Average) | 4 minutes & 57 seconds (Score: Average) | 9 minutes & 10 seconds (Score: Average) | |
| **Custom Questionnaire Score** | 161 | 752 | 805 | 93.4% |
| **SSQ Score** | 812.63 | 862.2 | 3250.51 | 26.53% |
| **SUS Score** | 0 | 90 | 100 | 90% |
| **ASQ Score** | 69 | 86 | 483 | 17.6% |

[b] In the Age and Time/Score fields, the minimum and maximum are the lowest and highest values attained, respectively, whilst in the other fields it states the minimum and maximum possible values attainable.

### C. Instruments

The instruments of evaluation used were compiled into a single Questionnaire, consisting of a general questionnaire for demographical analysis, a custom-made questionnaire for this application and three validated questionnaires, the Simulator Sickness Questionnaire (SSQ) [10], the System Usability Scale (SUS) [11] and the After-Scenario Questionnaire (ASQ) [12].

### D. Procedures

Each volunteer was sat on a chair in front of the stimuli device, given a briefing of the controls, and then equipped with the HMD. During the experiment, and using the observer's menu, the volunteer was assister throughout the experiment. When the experiment was complete, the evaluator took note of the score and time of the volunteer, and the volunteer was given a questionnaire to fill out.

### E. Results

In the sociodemographic questionnaire we could observe a mix of users with low, medium, and high experience in computer interaction, and even though some users had previous experiences with VR, more than half did not. Still in this questionnaire, the score for each user was retrieved, and all users managed to stay in the Average score (Good is under two minutes, Average is between two and ten minutes, and Slow is over ten minutes), with an average completion time of 4 minutes and 57 seconds, which is particularly good for a first interaction with the app. It is worth noting that this scoring method is purely subjective and of the authors' opinion, given the complexity of the actions asked, and made in order to understand if the user is improving with successive attempts, something that this study was unable to evaluate.

The first questionnaire, with questions better aimed at this application, in particular, has seven items, which attempt to find out if the app was immersive, if the external stimuli were effective, if the environment had good quality and if the user learnt anything useful with the experiment. The heat component was less effective in some of the tests, due to the elevated temperature of the testing room and the necessity of the stimuli apparatus to be at a certain distance from the user, so that the user would not hit the device. This questionnaire had a scale from one to five (totally disagree and totally agree, respectfully), with a minimum score of 7 and a max of 35 (in this case, the more points the better). Some of the questions had a negative connotation, and so their points were reversed. The max possible score was 805, and the score archived was 752, with an average of 32.7 points per user, leading to a good score of 93.4%.

The second questionnaire, the SSQ [10], in which the user must answer which symptoms out of sixteen he felt after the experiment, from one to four (1 is none, 2 is slight, 3 is moderate and 4 is severe) and the fewer points achieved the better the app is. This questionnaire has a complicated scoring system, as shown in diagram 1, and so the minimum score per questionnaire was of 812.63 and the max of 3250.51, with nausea average of 68.4 points, and an oculomotor average of 58.0 points, a disorientation average of 104.1 points and a cybersickness average of 862.2, meaning that most users did not feel any aftereffects of the experiment, with a total score of 26.53%. The most signalled option of all the questionnaires was ocular fatigue, which was most likely caused by the fact that the HMD used in the experience did not possess enough clearance for most glasses.

| Symptoms | Weights for Symptoms Nausea | Oculomotor | Disorientation |
|---|---|---|---|
| General discomfort | 1 | 1 | |
| Fatigue | | 1 | |
| Headache | | 1 | |
| Eye strain | | 1 | |
| Difficulty focusing | | 1 | 1 |
| Increased salivation | 1 | | |
| Sweating | 1 | | |
| Nausea | 1 | | 1 |
| Difficulty concentrating | 1 | 1 | |
| Fullness of head | | | 1 |
| Blurred vision | | 1 | 1 |
| Dizzy (eyes open) | | | 1 |
| Dizzy (eyes closed) | | | 1 |
| Vertigo | | | 1 |
| Stomach awareness | 1 | | |
| Burping | 1 | | |
| Total* | [1] | [2] | [3] |

Score
Nausea = [1] × 9.54
Oculomotor = [2] × 7.58
Disorientation = [3] × 13.92
Total Score = ([1] + [2] + [3]) *3.74

* Total is the sum obtained by adding the symptoms scores. Omitted scores are zero

Diagram 1. The calculations in the Simulator Sickness Questionnaire.

In the third questionnaire, the SUS [11], for evaluation of the usability of the app, is composed of ten items scored from one to five (totally disagree and totally agree, respectfully), where the ideal score of 100 points, and a minimum of 0 points. Of the twenty-three participants, twenty graded the app as “Excellent” and only 3 as “Good”, with an average usability score of 90, which translates to an excellent app, a great score in the evaluation diagram of the SUS questionnaire (diagram 2) sets the app in between the excellent and ideal scores, with very acceptable usability and within the fourth quartile range.

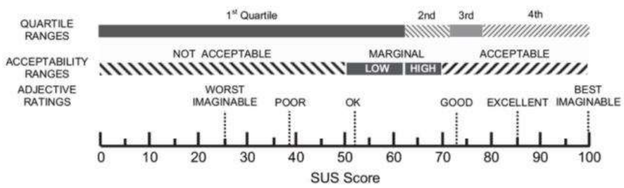


Diagram 2. The calculations in the Simulator Sickness Questionnaire.

The fourth questionnaire, the ASQ [12], measures the satisfaction of the users with three questions, graded from one to seven (totally agree to totally disagree, respectfully), in which the least points, the better the satisfaction is. Out of a minimum of 69 points and a maximum of 483 in the twenty-three questionnaires, the result was a score of 86 points, with an average of 3.7 points per questionnaire (Where the minimum is 3 and the maximum 21), resulting in17.6%, meaning high satisfaction with the app.

All of the resulting values were compiled into Table I.

## VII. Conclusion

This very current problem had a legit approach in a VR environment, making this a light gamified approach.

The results obtained in the questionnaires were good, given the time and purpose of the app, and two simple things that might have improved the results would be a small tutorial before using the app, and a slight adjustment in the interaction mechanics.

Some of the advantages of the app are the simplicity to use, with simple controls that require simplistic movements, the fidelity of the virtual environment in comparison with a real scenario, the options given to the observer to assist and guide the experiment and the simplistic scoring system, that will surely be of great use to determine how ready the user is to attempt assembling a real computer.

One of the challenges of this application are the creation of a mode where the assembly of the computer does not follow a linear pattern, allowing user faults and forcing him to notice these flaws. Another challenge will be a refined scoring system to go along with a new non-assisted option.

Future additions considered for this prototype include a non-sequential, non-assisted option could be implemented, as it would create a bigger challenge to those who already attempted the assisted version, the textures could see some improvement for better immersion of the user, the interactions should be polished, and a better scoring system for the new training option, where correct part position, time, and completion, are to be taken in consideration.

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# Generic XR game-based approach for industrial training

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***Abstract*—Over the years several Virtual Reality- (VR) and Augmented Reality- (AR) based learning environments have been proposed. However, they are usually built for a specified scenario and possess a very limited set of configurations. Moreover, the proposed solutions are designed solely to VR- or AR-based learning environments and only a few propose solutions that use both learning environments for training. The present paper proposes an approach composed by a training design methodology and a generic and configurable system for training operators of industrial production processes, which is able to adapt and evolve along time, following changes in the processes and/or machines/tools in an industrial environment. In order to increase the engagement and consequently the development of competences in the operators, a Game Based Learning methodology provided along with VR and AR is used in the training context.**

***Keywords—game-based, gamification, virtual reality, augmented reality, industrial training***

## I. Introduction

A VR environment provides a safe learning environment where the trainees perform tasks without being worried about damaging the machines or tools or harming themselves [1]. On the other hand, in a VR environment it is possible to simulate any kind of machine and all possible situations including hazard ones [2]. An AR environment allows trainees to work in a real environment and receive instructions on how to perform tasks [3]. VR and AR learning environments provide different features and usually are used with different aims. Both possess advantages, so a learning system that provides both is a more complete one. For instance, the VR learning environment can be used in an earlier stage of the training program, when the trainees do not have yet enough knowledge and experience to work in a real environment. The AR learning environment can be used in more advanced stages of the training program, when the trainees already have the necessary knowledge and experience to work or train in a real environment but still need some help.

There have been proposed several solutions and systems that provide VR- or AR-based learning environments. However, most of those solutions or systems are designed solely to provide a VR- or AR-based learning environment and only a few of them propose solutions that include both learning environments. Moreover, most of them were built with a specific scenario and objective in mind. A few solutions provide means to configure the training sessions but with a limited set of configurations. Mostly they focus on providing the possibility to define the content to be shown. When it comes to the simulation of the machines behaviour it is even more limited. This feature allows the system to evolve along time and adapt to changes in the processes or machines/tools. Thus, a complete training sessions configuration component is essential to guarantee that the training system adapt to changes. No solution has been found that provides a complete configuration component.

Traditional teaching processes, based, for example, on expository sessions and deductive learning (i.e. focused on the trainer), are not very efficient, especially in terms of knowledge retention, as trainees quickly stop paying attention. In fact, in [4] is shown that only 10 to 30% of knowledge is retained when traditional approaches are used and that this figure increases to 70% when active learning approaches (e.g. inductive, learner-centred learning) are used. Additionally, in [5] is shown that there is a 55% increase in effectiveness in assessment results when using learner-centred learning strategies (active learning). Thus, the development of learning environments based on new teaching or training approaches is fundamental to promote the involvement of trainees in the learning process itself [6]. In general terms, the concept of "gamification" contributes to the development of teaching or learning environments in which participants have levels of involvement and motivation similar to those they experience when they are involved in playful game environments [7]. According to recent studies [8] [9] [10] the use of learning environments that are more meaningful and aligned with professional practice enhance the learning process and contribute to the development of complex problem-solving skills, which is indicated by the World Economic Forum as one of the most important skills to develop for the jobs of the future.

Therefore, Game Based Learning (GBL) methodology can be used in a training context to increase the engagement and consequently the development of competences. Nonetheless, only a few of the existent solutions have tried to incorporate some features of this methodology on their learning systems.



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In this paper is proposed an approach composed by a methodology and a system for training operators of industrial production processes. Several concepts/techniques are involved, namely: (i) Instructional Design, Work-Based Learning and Gamification, (ii) Virtual Reality and (iii) Augmented Reality. The integration of all the concepts referred to in (i) and (ii) in order to develop and deliver an efficient training approach (methodology and system) is an innovative aspect.

The VR component aims to train the new operators of industrial machines, where they perform tasks and receive scores depending on their performance, thus materializing a gamification component, in order to be evaluated and improve their skills. The AR component aims to show information about a certain machine and help the operator to perform its operations.

The system has also a training management component, implemented through a backoffice, that allows to define or configure the training sessions, which can be tailored to the trainee profile, configure the VR training sessions, configure each machine or tool simulation (which allows the introduction of new machines in the training or the reconfiguration of the existing ones), and finally has the possibility to configure the AR training sessions.

The use of Game Based Learning will be implemented in training itself in order to keep learning motivation high. The goal is to engage learners from the training process beginning. The way how the game-based learning model is defined is also innovative. In this part of the training design process, scenarios are defined as challenges related to the "competences" to be developed and the problems to be solved. These scenarios or challenges are the essence of the Game Based Learning model. The training system will include learning objects (e.g. challenges) adapted to the different learning styles (profiles) of the trainees, allowing thus the personalization of learning paths which also consider the performance of the trainee during the training process. This is another innovative aspect of the proposed approach that will contribute to increase the efficiency of the training process.

## II. Related Work

The use of VR environments for industrial training has raised a lot of interest, resulting in several academic and commercial solutions. However, a large number of those solutions were built as customized solutions with a specific objective in mind, making very expensive and time consuming the update of existing training or creating new ones [11]. The same applies to AR industrial training solutions.

To alleviate the process of building VR environments, over the years, several authoring tools have been proposed and made commercially available. [12] present a recent systematic review on authoring tools for creating immersive environments and [13] present a survey on VR authoring tools for education. Typically, these solutions allow to: i) pick content (e.g. 3D models, 360 videos) from pre-existent libraries or, in some cases, import (upload) their own content; ii) create behaviour and interactions using a toolbar or a simple visual language; iii) (mostly in education cases) provide statistical data about participants' performance. In the case of authoring tools for AR the available solutions are even less and, in most cases, providing only basic features [14].

Besides these more general-purpose authoring tools there have been proposed and made commercially available a few solutions that allow to add gamification features to the training sessions.

CenarioVR [15] is a solution which has xAPI tracking features that work together with a dashboard that displays the tracked data in real time, and the user's progress can also involve a scoring system that can be applied to each of their activities.

PixoVR [16] is a solution that allows the creation of VR training scenarios based on these four premises: realistic practice, spaced repetitions, contextualized scenarios, and critical feedback. It allows multiple users to join in the same training session. Also, it exposes users to many different repeatable and randomized workplace scenarios, that include real time scoring and feedback. The content and users can be easily managed using the Pixo Apex dashboard, that can be accessed on a browser or on a mobile device app. Finally, the solution also provides cross platform support and in-depth data analysis in real time.

[17] proposes an adaptive, gamified VR learning environment for industrial scenarios. The VR environment is adapted automatically to each exercise by loading the resources at the beginning of the learning sequence. The adjustments are based on predefined CAD models. A level based visual guidance system increases the difficulty and complexity of the work tasks gradually. DAGs allow procedures that adapt to the user's actions. Key Perfomance Indicators (KPI) are used to evaluate user performance and transferred through points into the level system. Additionally, KPIs are used to figure out efficient work sequences that are transferred into real-world applications.

Patent [18] provides learned interactions in a virtual reality or augmented reality (collectively, a computer-mediated reality) and can include determining a probable physical action of a user interacting with a computer-mediated reality (CMR) environment. A learned interaction corresponding to the probable physical action can be generated based on a CMR-physical action (CMRPA) model that correlates physical actions with results of the physical actions in a CMR scenario of the CMR environment. In response to determining, based on at least one identified characteristic of the user, a statistical likelihood of benefiting the user by providing the learned interaction, a learned interaction corresponding to the probable physical action can be provided to the user.

## III. Generic XR game-based Training Approach

The proposed approach is composed by a methodology and a system for training operators of industrial production processes, which is grounded on instructional design and a game-based learning strategy. The proposed methodology is oriented by Instructional Design, which is based on the ADDIE concept, an acronym for Analyse, Design, Develop, Implement, and Evaluate, which are the stages for a training program. Thus, the formation process was mapped so that operations are organized in the phases foreseen in the ADDIE concept. The proposed methodology resulted from a thorough analysis of the formation process and from the feedback provided by domain experts, in our case trainers and training managers.

The detailed survey of requirements for the development of the training system for future employees, as well as the identification and characterization of the competences to be developed by those employees, uses tools that are not being used in this area, namely BPMN (Business Process Modelling and Notation) and Ishikawa Diagrams. The training team (training managers and/or trainers) identifies competences from the process characterization, represented from the BPMN modelling procedure, and also based on the survey and classification of occurrences (e.g. problems in the production process) through an Ishikawa Diagram (Fig. 1).

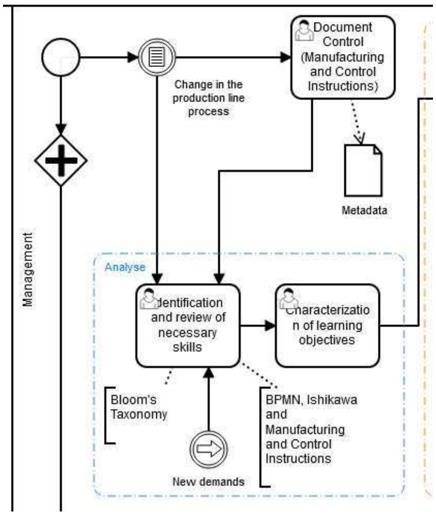


Fig. 1. Competences definition process

The creation of challenges (scenarios) is carried out by the training team, considering not only the desired competences (identified through BPMN and Ishikawa diagrams) but also the trainees' learning styles (classified according to the Felder-Silverman model) (Fig. 2). Challenges are defined so that trainees develop competences to deal not only with the normal operation of the process, but also with the problematic situations that may occur (e.g. machine breakdown). A game-based learning approach is used, incorporating virtual and augmented reality, to simulate machine operation scenarios.

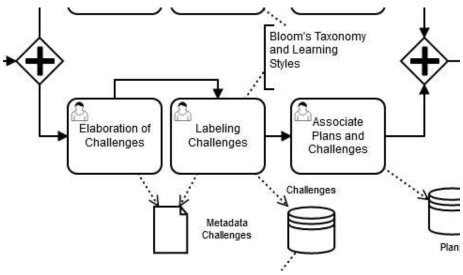


Fig. 2. Challenges creation process

The proposed approach has two fundamental characteristics: personalization and adaptability. The personalization of the training environment corresponds to the presentation of an environment according to the preferences and characteristics of the trainees (learning style). Adaptability includes the training environment configuration according to the performance and needs of the trainees as they interact with the training system. Learning objects are the elements that make it possible to implement these characteristics and may include: virtual reality and augmented reality resources, videos, demonstrations, exercises, assessments, statements, references, topics, lists, graphics, images, emails, discussion forums, among others. The environment will be geared both to classroom training and to support the trainee in the execution of operations in a real environment (Fig. 3).

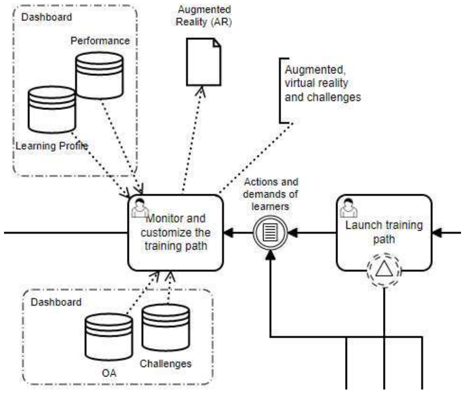


Fig. 3. Process of personalization and adaptability of the training course

The training system (Fig. 4) is composed by three main modules: the VR application module, the AR application module and the training manager module that includes a task configurator and an XR configurator. These modules, together, define the system, satisfying all the system's needs. Each one of the modules is divided into other components that, through the external Communication Management component, communicate with each other using webservices.

The system has two main types of users: the training manager, which is responsible for defining or configuring the training courses, and the trainee, which will attend the trainings.

The training manager uses the training management application to access the profile of the trainee in order to obtain relevant data about them, to customize VR/AR training sessions in order to add or edit content and adapt as necessary, and to add or edit the objects (e.g. machines, tools) according to the needs of the trainings. All data managed through the training management application will be stored in a dedicated database.

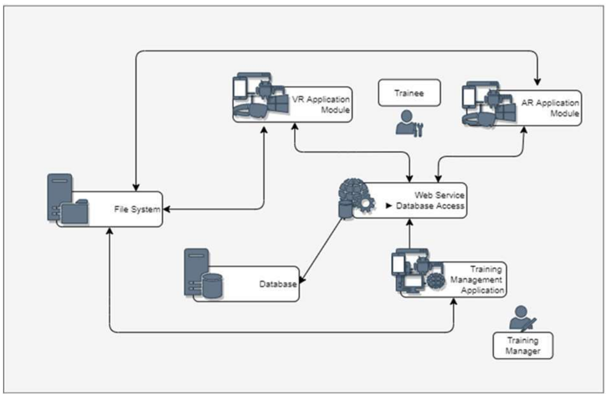


Fig. 4. Training System Architecture

The trainee will use the VR and AR applications to learn and train the steps needed to operate the machines. All data involved will be obtained or entered into the database. The access to the data (write or read) will be through dedicated webservices.

The VR application module (Fig. 5) is divided into 5 components. The Gamification component is the one that will give the application its game characteristics, such as a points system, and will interact directly with the VR Task Executor and Communications components. The VR Task Executor component is responsible for managing the training tasks, which will worth a certain number of points, depending on how well the trainee performs the tasks. The Machine Simulator component will receive the files related to the machine, such as 3D models and animation setup files, to create a virtual machine with characteristics similar to the real machine. The Physical Interactions Simulator component will use the files related to the physical feedback that the user will get when interacting with different virtual objects by using the VR gloves with force feedback. The Communications component will interact with the other system components, like the WebServices and FileSystem components. This later component is needed in order to have access to files that are being hosted in the database. The Machine Simulator and the Physical Interactions Simulator components will also need to have access to some files to perform their part of the job.

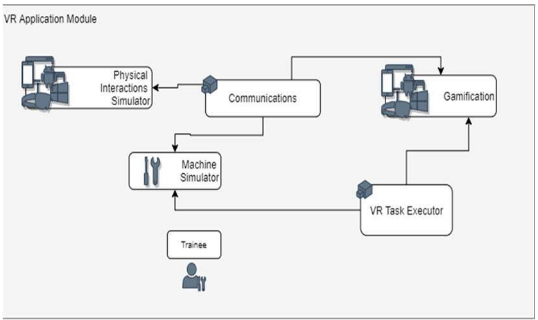


Fig. 5. VR application module

In the AR Training module (Fig. 6), the Trainees can visualize the contents associated with their training. The Trainees may select the training content topics that they need or want to see at a given moment. All data generated from this module is interchanged with the communication system component, which communicates with the webservice system component.

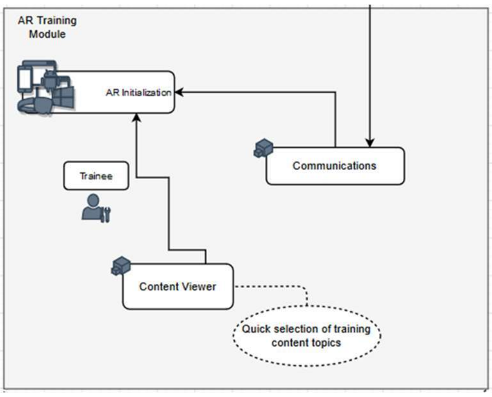


Fig. 6. AR application module

## IV. Training System Prototype

Fig. 7 presents the training system prototype architecture.

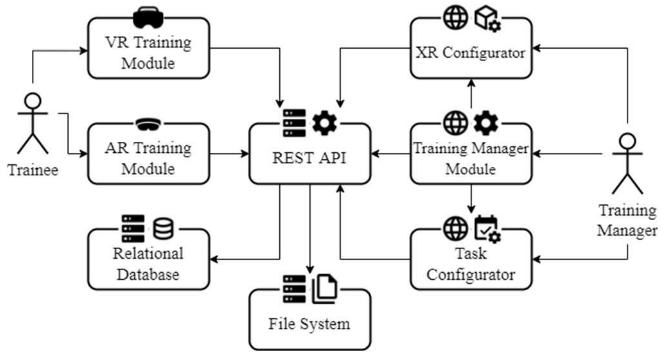


Fig. 7. Training system prototype architecture

### A. Training manager module

The Training Manager module presents a user interface, developed using Vue.js JavaScript Framework, which simplifies CRUD operations to the training database. To connect to the database a REST API was developed in PHP using the Laravel framework. This API makes the bridge between all clients (applications) and the database.

The Training Manager module allows to manage data about courses plans, training courses, objects (e.g. machines, tools) and content (e.g. video, images) to be shown. During the training course configuration, besides entering information about the training course, the user should use the Task Configurator to define the valid sequence of tasks and the XR Training Configurator to define what is presented and configure the interactions for each task.

Lastly, it is possible for the trainer to access statistical data, in the form of graphs, that can help him to identify problems related to the execution of the tasks. It is also possible for the trainer to have a closer look at the data by interacting with the graph. By selecting a specific Learning Object, a second graph is presented that shows the points per minute achieved by each individual trainee.

### B. Task Configurator

The Task Configurator is a WebGL application which allows the setup of the base tasks used in both the AR and VR Players, as well as how strictly they must be followed in the gamification component.

These tasks are set in a flowchart editor, where to each task is assigned a flowchart that must be composed with a sequence of Steps (process shapes) and Conditions (decision shapes), linked with lines and delimited by a Start and an End shape, exemplified in Fig. 8. Flowcharts may also be complemented with labels in the canvas and in Conditions' exit lines.

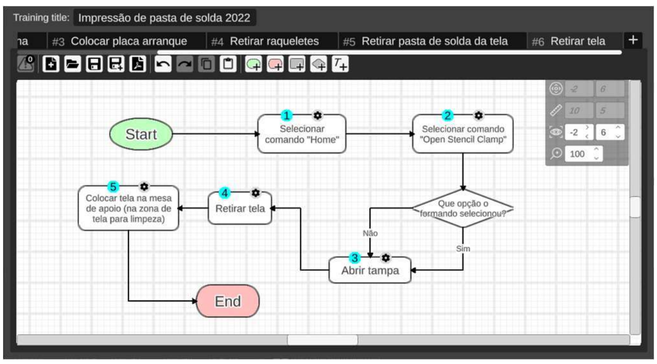


Fig. 8. Task Configurator's Flowchart example

This configurator includes general commands to ease the creation of flowcharts, which can be accessed through:

- Mouse gestures in the canvas – to select, move, resize and link shapes, labels and lines, and to move and zoom the canvas' camera.
- Toolbar and hotkeys – to access warnings, save changes, export to PDF, undo and redo actions, copy, cut, duplicate, paste and delete selected shapes, labels and lines, and add shapes and labels.

To link two shapes, one of the 8 linking nodes (4 sides and 4 corners) from the exit shape must be dragged with the mouse, instantiating a step-shaped line with an arrowhead. The tail of the line is left at the exit shape, placed at one of its linking nodes, while the arrowhead is dragged by the mouse until being dropped at the entrance shape, having a linking node assigned. Both the exit and entrance nodes are automatically assigned based on the shapes' relative positions, in order to have the shortest path and to prevent it from overlapping the shapes they're linking.

Fig. 9 shows that to each step can be assigned a list of constraints that must precede it in the Precedences menu. Such restrictions refer to steps from the current or previous tasks that must be performed beforehand. These restrictions have three types – Natural Precedence (can't be physically performed without the referred step's conclusion), Penalization (the user is penalized if the restriction isn't followed), and Game Over (if not followed, the user immediately fails the task).

Through the Precedences menu, points can also be set for each step, awarded upon their conclusion, if its precedences allow it.

When the flowchart's composition doesn't follow the proper flowchart structure rules (for example: missing Start or End shapes, no exit link in a Step shape, etc.), the flawed shapes are highlighted with red outlines, whose flaws are revealed through the warnings button from the toolbar.

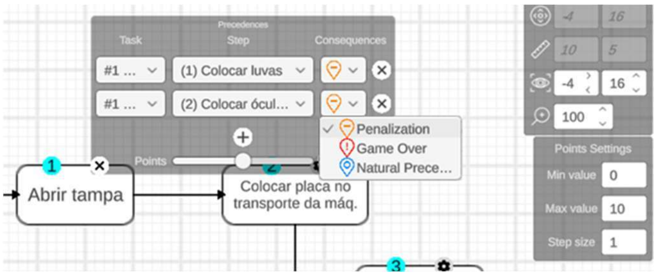


Fig. 9. Task Configurator's Precedences menu

PDF exportation generates a PDF file, composed with A4 pages filled with each task.

Saved projects are sent to the API and all its logic is stored in the database, for future use by the XR Training Configurator.

## C. XR Training configurator

The XR Training Configurator's purpose is to setup the steps' annotations and interactions that feed the AR and VR Players, as well the scenario regarding 3D models, which are part of the training context and must be part of the VR Player's scene. Annotations are used to provide contextualized feedback or guidance to the user.

As a point of reference for annotations' placement, useful mostly for the AR Player, an image marker is defined with customizable size, position and rotation.

Each scene's 3D model and all of its components have their properties accessible and customizable (Fig. 10), processed mostly by the VR Player, namely their position, rotation, scale, textures (from an images catalog available through the API), visibility, forces type (none, regular (affected by gravity) or kinematic) and interaction type (none, collider, trigger only (components pass through it but can still invoke triggers)).

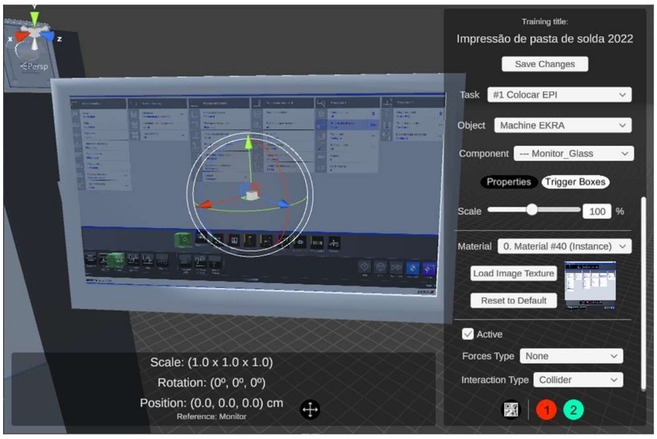


Fig. 10. XR Configurator component properties

Each component can be given multiple trigger boxes as their children, allowing interactions in specific parts of a component, like buttons on a screen texture, being invisible in the Player view.

Regarding steps, their annotations are displayed in the VR Player's training mode and in the AR Player, and are anchored to an arrow pointing towards the area where action must be performed. Both their position and rotation use the marker as a point of reference.

For each step, a set of annotations can be anchored to the arrow. The catalog of available files is accessed through the API and may contain text boxes, PDF files, 3D models (Fig. 11), images, videos and audio clips.

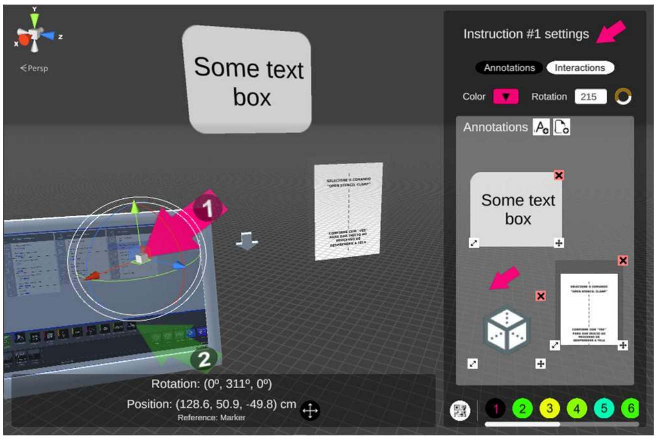


Fig. 11. XR Configurator annotations

For each step a set of interactions can be defined through input and output actions, relevant only for the VR Player. A step's conclusion is triggered when its input action is performed, which consists of a trigger between two components. Besides concluding a step, a set of other output actions can be defined, namely an animation of a component, defined through the Animator, texture change of a component's material, visibility of a component, forces type of a component, interaction type of a component, or cancelation of any step from any task.

The training project's serialization is sent to the REST API and stored in the database to be accessed from the AR and VR Players.

The XR Training Configurator also includes an XR Animator, which allows trainers to create animations for the machine models that will be shown in the VR Player application.

The XR Animator allows trainers to record animations like simple movements (rotations, translation, etc.) of objects or components of a 3D model, as shown in Fig. 12.


Fig. 12. XR Animator overview

While animating an object, a path with position and rotation changes over time is generated which represents the animation, which can be played.

## D. *VR training module*

The Virtual Reality player application is used by the trainees to perform their practical training sessions (Fig 13). The hardware necessary to use this application is an HTC Vive HMD and the SenseGloves with trackers. The use of this VR gloves allows the trainees to have an experience more similar to a real one, regarding object manipulation tasks. To execute this application, it is important to be in a room with enough space to walk and move the arms around without hitting any obstacles.

Fig. 13. Trainee using the Virtual Reality player

The trainee, after login, will choose one of the training sessions associate with him. For each training session he may choose to simply train (it will be shown instructions on how to execute the task) or to perform the evaluation (no tips are provided), in which case the final score is used to define if he is approved or not on the training session. The virtual scene is built in runtime based on the configuration data that was defined for the training session chosen by the trainee.

All the interactions done within the Virtual Reality Player provide haptic or force feedback through the gloves that the user is wearing. This feature was achieved by using the Unity Engine colliders. Simple touches will only provide haptic feedback, and item grabs will provide both haptic and force feedback. To perform animations, the app also uses these colliders to know when to trigger the animations.

At the end of each session, the app will create a report where all the statistics tracked during the whole process will be displayed, like the task duration and points. All this data is stored in the training database.

## E. *AR training module*

The Augmented Reality player application may be used by the trainee, in the working space, to have help about how to execute the tasks or review some training content (Fig. 14). The AR app runs on the Microsoft HoloLens 2 headset. This application was developed in Unity3D, using Mixed Reality Toolkit from Microsoft.

To be able to attach correctly virtual contents to real objects or places, first there is needed to know where the user is. The HoloLens 2 has a feature called Spatial Mapping which, as the name says, tries to understand the space around the user by creating a virtual mesh that can be used to anchor virtual content. This feature is one of the most important features, because it allows the worker to navigate within the virtual space at the same time as he walks in the real environment. However, we still need a technique to instantiate the virtual process (the virtual annotations) on the correct spots, by attaching them to the correct physical objects or places. To that end, we need to add a jumpstart point to the application, which means that the application needs to be able to recognize a certain pattern or object to start the process correctly. This can be done in two ways: using object recognition techniques or marker detection. The first is obviously better because it doesn't require a specific pre-setup of the real environment, since the application will detect an already exiting object. Unfortunately, this kind of functionality is very expensive, and it is always blocked behind a big annual paywall. This is why we implemented the second technique (marker detection).

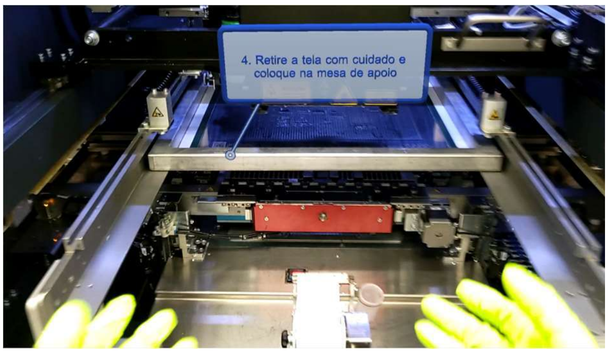


Fig. 14. Trainee using the Augmented Reality player

Marker-based detection have been around for many years. This functionality is used in most of Augmented Reality projects because it is easy to configure, accurate and most of the times it is free. Still, initial research suggest that natural markers detection is not available to HoloLens for free. Although there are some paid SDK's that allows the detection of natural markers, our team is aiming for a solution completely free of charge. In the absence of a free technology that supports Image Tracking functionality on the HoloLens, we focused on using QRCode detection functionality.

A first prototype hardcoded was developed and tested on the field to gather first impressions and knowledge.

The app was developed with an easy and intuitive interface as the main goal. To achieve that, the virtual content layer must be well integrated with the surroundings of the user and supply the needed information using the less space possible to be helpful rather than annoying.

In the first step, the trainee needs to authenticate. After the authentication, the trainee is presented with a scrollable list of available trainings where he can participate.

Once a training is chosen, it is time to identify the machine position through detecting the machine QR code. This step allows the system to know where the machine is and consequently where each virtual content needs to be located.

With the machine position defined, the system gathers the information associate with the training by using the REST API to connect to the training database. The response is a list of tasks with all their details (steps, multimedia contents …). The user has the possibility to navigate through the tasks information and choose the one he wants to perform. To help with this process, the name of each task and details about each step is displayed.

At this point the trainee can start the execution of the task by pressing the "start task" button, which reveals the multimedia contents of the first step. Once the contents are shown, the user needs to perform the demanded actions. To progress in the execution of the task, the user needs to manually jump to the next step. This is done by selecting the "next step" button, which is revealed by looking at the palm of the hand. This hand tracking feature is provided in the Mixed Reality Toolkit.

The current supported types of contents are: PDF files, videos, image, audio tracks, simple text and 3D Models. For each content type there is a different container that it is responsible to download during runtime and show the content associated.

When the trainee reaches the final step, in the hand menu appears a new button which allows the trainee to return to the tasks list to select another task for training.

## V. Preliminary Test

In this section is presented the practical use case that was used to test and validate the training system in a real scenario. This use case corresponds to a subset of a real one that is currently run in Bosch Braga plant and used in current training sessions. Unfortunately, was not possible to test the system with users due to time and pandemic restrictions.

The selected use case corresponds to the Paste Printing Process. More precisely, we focused on implementing the first 6 tasks. First it was done a tasks analysis stage where it was identified, for each task, the 3D models or objects (machines, support desks, consumables and tools) and multimedia content (videos, images, sounds, texts, pdf files) needed. It was necessary to gather or build all the assets needed. In a second stage they were identified the interactions needed and the corresponding animations.

After gathering all the information needed it was used the Training management application to insert all the data regarding the training session, and configure the tasks and training using the Task Configurator (Fig. 15) and the XR Training Configurator (Fig. 16). All the data and configurations were done with success and the feedback received from the training team was very positive.

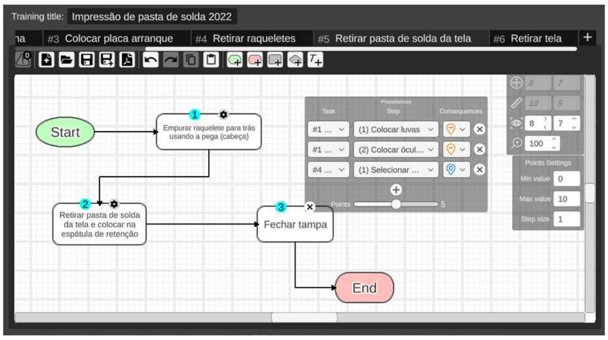


Fig. 15. Task #5's flowchart and one of its steps' precedences

Finally, some tests were done using the VR player and the AR player, and again the feedback from the training team was very positive.

## VI. Conclusions and Future Work

In this paper was presented a complete approach (methodology + training system) for industrial training that: i) is grounded on instructional design and uses a game-based learning strategy; ii) is generic and configurable, which allows to be applied to different scenarios and updated when it is necessary; iii) uses VR training scenarios in earlier stages of the training program, allowing the trainees to train without worrying about damaging any equipment and train in a safe environment; iv) uses AR training scenarios to assist the trainees in more advanced stages of the training program when he already has gathered enough knowledge and autonomy to work in real scenarios. Still, the implemented gamification strategy is a first illustrative proposal that should be further evolved by considering the target audience and use patterns of the proposed approach.


Fig. 16. Trigger box for the Home screen Button

A fully functional prototype was developed, and the preliminary test allowed to verify its suitability to define VR and AR training scenarios and its capacity to be used in real training scenarios. However, the approach and its training system needs to be tested in more use cases and with users (trainers and trainees).

In the AR training scenarios, there is the need to have a QR Code to act as the origin in order to place correctly the virtual objects. As future work it is planned to overcome this limitation by developing our own object recognition algorithm, which will allow to automatically recognize the object of interest and correctly positioning the virtual objects. Besides we also intend to do an extensive evaluation of our approach by testing it with several uses cases and users (trainers and trainees).

## ACKNOWLEDGMENT

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