

# A Method to Interactive Simulations of Industrial Environments Based on Immersive Technologies

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## Abstract.

Mixed reality technologies and digital twins have been widely applied when the objective is to create immersive virtual environments, especially when it comes to the industrial context. Industries are increasingly looking for ways to update the new 4.0 reality and, with the use of scenario's virtualization technologies, it is possible, for example, to train employees or people responsible for the development and creation of new solutions to digitalization in production systems for stakeholders. In this context, the article presents a project for the application of mixed reality and digital twin to create an immersive virtual environment for training employees at a company focused on the electromechanical area, more specifically on the maintenance of machines and equipment for the electrical substations at the headquarters located in the city of Curitiba - Brazil. The application's environment, in the diary activities, cannot be accessed with a certain frequency due to risks and the impossibility of stopping the manufacturing process. Thus, the work proposed a method to create immersive training sceneries based on Microsoft Hololens technologies in order to prepare the employees to be able to act on maintenance after virtual training.

**Keywords:** Digital Twin, Mixed Reality, Industry 4.0.

## 1 Introduction

The constant technological advances allow us to look for adaptative tools faces the need to find the successive solutions and improvements to avoid the recurrent problems in the industry and services. The competitiveness has always been an engine for the companies to adopt resources that allow them to achieve a greater advantage over their main competitors. There is an innovative human-centered evolution by digital transforming and the virtual environments play the role. The main idea of implementing immersive technologies in the industry is to help employees to comply with their work processes carried out on the shopfloor, as well as ensuring their safety. This implementation has been happening by Virtual Reality (VR), Augmented Reality (AR), Mixed Reality (MR) and Extended Reality (XR) technologies [1]. They are increasingly accessible due several aspects, such as: cost reduction, ergonomics, usability, less technical barriers to implementation, and maintenance facilities. Through AR and VR, employees can simulate its diary situations, as well as predict occurrences (accidents,

equipment breakdowns, etc.). In addition, the “digital twins” are another technological area that have enhanced the experience of both collaborating students and the company, since it is possible to virtually simulate the behavior of equipment in real time through the operation carried out. As presented in Figure 1 by the NTL Institute for Applied Behavioral Science [2], the learning pyramid points out that the practice reaches the level of 75% of content fixation, while the audiovisual reaches 20%; and reading and lectures reach around 10%.

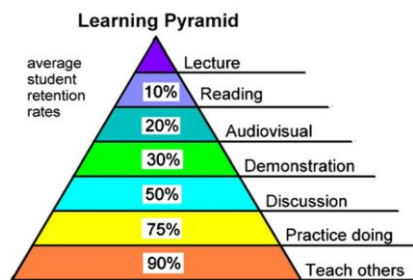


Figure 1. Adapted of The NTL Learning Pyramid [2][17].

We expect that a realistic simulation environment achieves the similar rate as the real practice. A simulation training offers a controlled virtual scenario for the professional to practice activities with risks involved, encouraging him to make an assertive decision. The main objective of simulation is precisely to offer interactive and intelligent systems, based on visual graphic tools, for the user to immerse and explore reality under stressful conditions. Simulation based learning breaks the learning paradigm by allowing the student to have a more active participation than traditional theory. Simulation learning makes use of software, VR and AR devices (3D glasses, swivel chair), graphic (games), sound (and even olfactory, depending on the training) resources. Our objective with this research project, is to create a method to virtual training focused on maintenance. We explore an example application to be developed in a German multinational company, in its Brazilian branch. Among the problems listed by the company's managers, the most critical one involved the plant's main substation: the “SD-01 69KV Substation” (Figure 2). The substation is responsible for distributing electricity to 14 other existing substations, and based on this care, it's clear that it is a critical point for the plant's operations. Every year there is a scheduled shutdown (lasting 3 days) for maintenance of the substation and verification of components. However, unscheduled downtime for maintenance interrupts the operation of machines and equipment responsible for the factory's production processes, resulting in a very high financial loss estimated at a few million dollars per hour/stop. The causes of unscheduled stoppages are diverse: pieces of objects/animals that fall into the environment causing a short circuit, heavy rain in a short period of time, burning of an electrical component, overload in the system, among others. Due to the risks involved in carrying out face-to-face training (in the environment), employees end up not being trained, resulting in a longer period of unscheduled downtime (when it occurs). Another point is the time to detect the root cause. As much as the maintenance technicians know the basic operation of the substation, regardless of the cause of the shutdown, for safety reasons the entire area is de-energized for inspection. Another critical factor is the

absence of a formalized history of unscheduled shutdowns and their respective causes, with no “lessons learned”: making it difficult to predict failures.

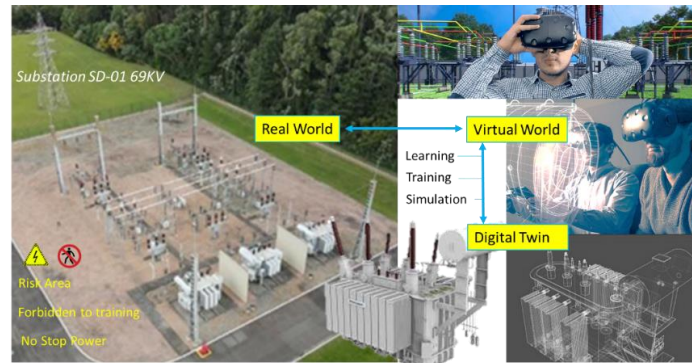


Figure 2-Conceptual features to digital twin.

## 2 Background

For some learning situations, especially when they involve skills development, the practical contact with equipment, environments and phenomena are the best way to learn. Using real environments is not always feasible or safe. Virtual reality (VR) and augmented reality (AR) are excellent alternatives in these cases. Furthermore, the natural evolution of computational interfaces should transform environments, currently graphic and two-dimensional, into immersive and three-dimensional ones, increasing the demand on the part of industries for interfaces of this type. Regarding the literature review, having already defined the research theme, we identified the main keywords such as: *interactive simulation*, *virtual reality*, *augmented reality*, *mixed reality*, and *digital twin*. We addressed the SCOPUS platform to search for relevant articles, reviewed by pairs and from the last five years. We also defined/applied, for the selection of articles, some inclusion/exclusion criteria such as: publication phase, type of source, thematic areas, keywords and classification of articles according to the Scimago Journal & Country Rank (h index). In addition, the articles were analyzed considering the conversion of titles and abstracts in order to select articles that would be read in full and used as a basis for the research. According to literature review, we can apply immersive technologies because the following characteristics:

The convergence between the physical and virtual worlds. The [3] addresses the impossibility of visual inspection and the complexity of combined loads make it difficult to quantitatively assess (difficulty of accessing a certain environment) and the [4] presents the challenges of high-quality scanning as it requires a comprehensive description and real-time rendering of the system. Also, model-driven digital twin system as presented by [4], is based on the descriptions of geometric, physical and sequential rules to produce an accurate and real-time simulation, as well as, according [5] a catalog of components and intelligent data models as a solution for the development of any digital twin. This disruptive convergence tends to augment

operations and services traditionally restricted to physical spaces with new virtual-based capabilities.

- The issue of human motor skills. Once the traditional hands-on training is resource and labor intensive, and the virtual training based on video demonstrations have the lack of interactivity, the [6] addresses the importance of developing remote training methods providing effective sensory feedback. For Buchmann [7], interaction consists of the user's ability to act in the environment in order to promote changes and reactions to their actions, which can bring performance gains as the user interacts more intuitively with the system.
- Also, the [8] propose the use of a virtual reality digital twin of a physical layout as a mechanism to understand human reactions. Finally, in the [9], simulation is approached as a technological tool for the development of exploratory and planning models to optimize decision-making.

## 2.1 The Problem

The training currently carried out at the study site does not use any immersive technology. The improvement of employees in electromechanical maintenance is carried out by instructors/technicians who have been working in the area for a longer time, as in figure 3.

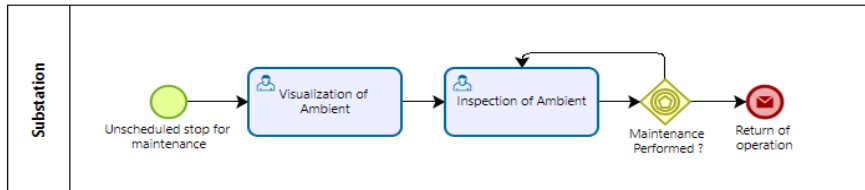


Figure 3- Workflow (no immersion)

An example of training that we can approach is for detecting electromechanical failures in circuit breakers. In 2020 the company reported that, after completing a scheduled maintenance shutdown, a circuit breaker was not resetting. However, it took the technicians approximately two hours to discover that the problem was caused by this circuit breaker and that it was due to a mechanical failure in its mechanism. Furthermore, after performing a fault analysis, another probable cause for the tripping of the circuit breaker could be the existence of a current value above that specified in the device. With that in mind, we thought about the possibility of carrying out training aimed at measuring current in the substation electrical network using ammeters or multimeters (for example). Positive points in carrying out training using a virtual environment:

- Work at height simulation
- Simulation of electrical measurement with the network powered/energized.
- Technical analysis of devices belonging to the environment.
- More time for employee training.

## 2.2 Immersive Technologies

According to [10], the immersive technologies refer to technology that attempts to emulate a physical world through a digital or simulated world, creating a surrounding sensory feeling, thus creating a feeling of immersion. The system uses VR to simulate virtual operation scenarios and interactions to provide an immersive operation experience. In this same context, the mixed reality connects and combines the physical and digital worlds in virtual and augmented reality applications. In visual terms, mixed reality can be defined as a creative space that exists between the extremes of the physical and digital world. Experiences range from superimposing virtual content on objects in the physical world, as in augmented reality apps, to a fully immersive experience where the user has no real-world participation, as in virtual reality.

To increase the sensation of immersion, mixed reality systems use dedicated hardware that is more powerful than traditional cell phones and tablets, in addition to having sensors capable of rapidly scanning the environment around the user in 3D and making virtual objects interact with the identified geometry of the site. The most complete systems use special glasses, with semi-transparent lenses, where virtual objects are projected in perfect alignment with the environment, which causes a very realistic illusion of the presence of these objects.



Figure 4 - (a) Digital environments that shut out the real world. (b) Digital content on top of your real world. (c) Digital content interacts with your real world. [10]

Mixed reality environments are created by combining objects into a single environment. Real objects can be captured by various means, such as: 3D scanning or photogrammetry. Meanwhile, virtual objects can be created using computer-aided design (CAD) software. Photogrammetry is a technique that allows the study and definition of shapes, dimensions and positions of objects in space, using measurements obtained from photographs or digital images. According to Kempter [11], 3D laser scanning and photogrammetry technologies are the digitization technologies most used for surveys of buildings and, despite differences in cost of equipment and processes of detection, are three-dimensional automated and wireless acquisition systems, contact with the analyzed object, which use sensors based on waves of light for the measurement, direct or indirect, of the object.

These processes generate files that can be migrated and manipulated using augmented reality glasses such as, for example, Microsoft's HoloLens 2. Using these glasses, the user can interact with virtual objects (holograms) and place them on something physical, like a real table, to visualize parts, for example. A point to consider regarding HoloLens 2 is the possibility of connecting to Microsoft Teams, in which the person can use the glasses to talk to a professional who is in another distant environment, and who

will give instructions for maintenance on a machine, also through Teams. This device creates [12] high definition virtual environments, allowing interactions between augmented reality and the user.

Directing to our problem, we can use these glasses for the interaction between the students (collaborators) and the virtual environment in which it will be possible, for example: the measurement of electrical variables, exchange of mechanical components, continuity tests, simulation of failure situations electromechanical and etc.



Figure 5 - User view through HoloLens 2, adapted from [13].

However, before importing the files (generated through photogrammetry or 3D scanning), it is necessary to use some software that prepares the 3D models (modeling, rendering, animation, creation, and visualization of interactive 3D content and etc) for use on the glasses. Among them, we researched: the Blender and Unity.

With Blender it is possible to crop and configure the captures and smooth textures and edges to obtain the best model. From Unity, we can turn 3D scans into animations or create scenarios. In addition, we can edit and combine them however we want. Both software communicates making it possible to export files between one platform and another.

### 2.3 Digital Twin

We can define digital twins as virtual models of a product or asset connected to the physical prototype or instance via the Internet of Things (IoT). Digital Twin is a relatively new trend which comprises building a simulator of a product, processor or machine, being powered by real sensors and (in real time) the existing device. The advantage of this concept is not only to monitor its operation, but to simulate different usage situations, improvements, failures, etc. Thus, when necessary, intervention is much more effective [14][15].

Essentially, digital twin is a hybrid approach, built into four levels [9]: geometry, physics, behavior, and rule. The first two levels involve mainly kinematics and geometric simulation, also referred to as continuous simulation.

Using Hololens 2 [16], mentioned in item 2.2, we will apply the concept of digital twin, considered an efficient intelligence solution for digitization and automation that uses [3][21] digital models to monitor, describe, simulate, predict and control physical counterparties in a timely manner.

### 3 Proposed Method

The research project proposes the development of a digital twin for training employees who are responsible for the maintenance of the substation in question. The development of maintenance skills involves several high-risk activities such as: work at height and high voltage. Activities that end up not being realistically trained on a daily basis due to the existing risk. Through a digital twin, it is possible to simulate/virtualize the scenarios and, logically, the possibility of carrying out employee training without offering risks to the integrity of people. Along with the digital twin, augmented reality and virtual reality features will be used. In Figure 6, we briefly describe the steps of the proposed method.

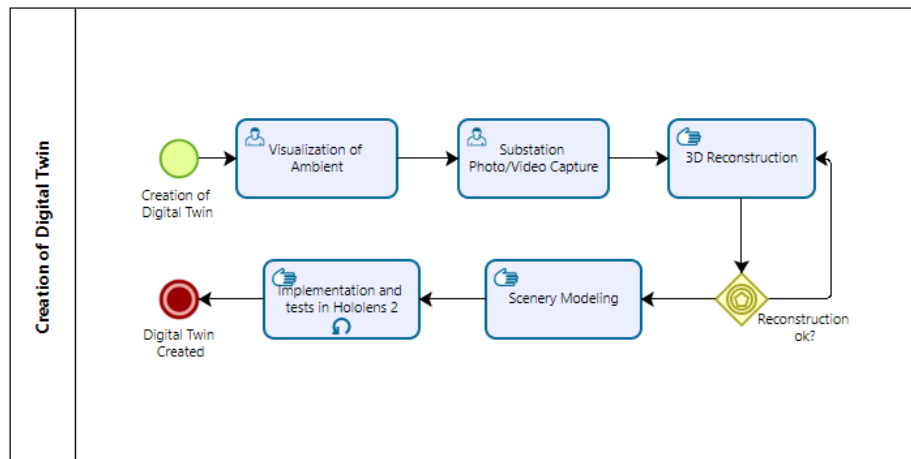


Figure 6 - The proposed method with the respective steps for training through the digital twin.

#### 3.1 Visualization of the Ambient

As for the implementation of the proposed method, initially a face-to-face visit will be made to the study environment (substation) for space analysis and planning for the next step: substation photo/video capture according image processing requirements [17][18]. A next step is the analysis of physical variables present in the real environment with the aim of implementing them in the virtual world.

### **3.2 Substation Photo/Video Capture and 3D Reconstruction**

In the stage of capturing photos and videos of the substation, we will use an Iphone model 13 pro through the Polycam application. We have already carried out some preliminary tests and obtained satisfactory results. To create the virtual environment (mixed reality), it is necessary to reconstruct the physical environment in 3D, based on the captured images. A solution for 3D reconstruction is the use of some software or application that performs the process and provides us with the 3D environment for the next steps. We checked and chose two softwares for a more detailed analysis in practice: Polycam and Meshroom.

Meshroom is capable of producing sharp and accurate models, but requires a lot of processing power and storage, generating heavier files. While Polycam creates high quality 3D models from photos with any mobile device. It is possible to view the 3D captures directly on the device, and it is also possible to export them in various file formats. A point of attention is that Meshroom is only available for Windows and Linux, while Polycam only supports mobile devices (IOS/Android).

### **3.3 Scenery Modeling**

After the 3D reconstruction, we will use the Unity software, which is a tool that allows you to create video games for different platforms (PC, consoles, mobile, VR and AR) using a visual editor and programming through scripting, offering users professional tools, capable of fulfilling the requirements of any game. Some factors related to the real environment are important with regard to virtual modeling: risk sequence, kinematics, physical simulation (if possible) and, finally, special effects to show the consequences of the electromagnetic fields existing in the environment in question (substation)

### **3.4 Implementation and tests in Hololens 2**

With the scenario modeled, we will carry out the implementation and tests using Hololens 2 [14][20]. We will have the support of the company's own employees for this step. From this, we will have feedback regarding usability, reliability, practicality, etc.

## **4 Results**

From proposed method we simulated in laboratory the 3D reconstruction process, from acquisition of the image of an electrical transformer. Despite the scale difference, we intended here to validate the 3D image acquisition. As shown in the image of the figure 7.a, we extract the measures by manual way as reference to validate the object size.

In figure 7.b is presented the respective reconstructed image after all steps executed of proposed method. It is observed distortions on extreme points of the objects. We observed that we have the same pattern in sizing, however, the distorted parts of object changes with rotations in the virtual environment as presented in figure 8.



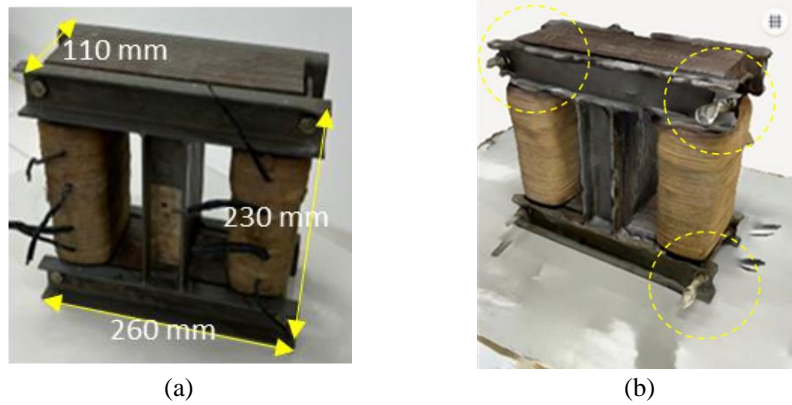


Figure 7 – (a) A 2D image of a real electrical transformer (260mm x 230 mm x 110 mm). (b) The respective 3D reconstructed image.

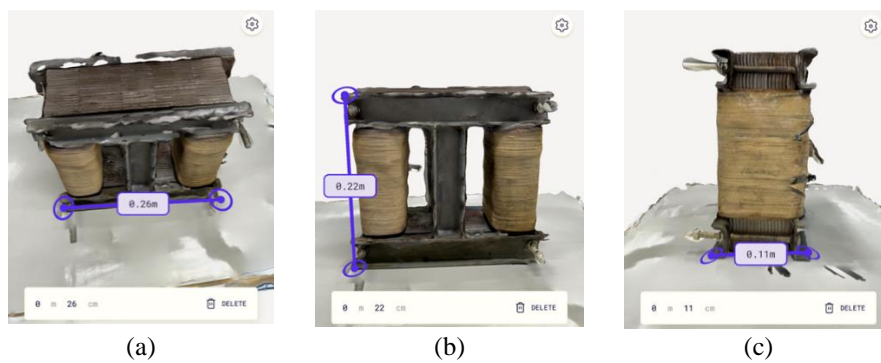


Figure 8 – The three views of the reconstructed image. (a) top view. (b) front view. (c) side view.

As this article deals with a proof of concept, in which we evaluate the technologies that can be applied in the creation of the environment, we do not have quantitative technology evaluation data. However, qualitatively we can say that the use of the Polycam application was satisfactory because it gave us expressive results with regard to image quality and fidelity with the real object.

## 5 Conclusion

As presented in this article, we select eight main articles that used some of virtual technologies for study and/or practice. The examples found deals about the impossibility of visually inspecting underground objects by applying augmented reality to create a corresponding digital twin. This kind of problems has in common with our research, the impossibility of accessing the environment due to external risk factors.

Also, we are concerned to prevent the humans' actions in sharing a common workplace due the impossibility of access by employees to the environment while the equipment is in full operation; The creation of a digital twin connecting to a 3D model arose too because [4] from the 3D graph generated by the 3D model it is possible to extract the various information relevant to the physical twin, such as: shape, size and positions of the objects present. In addition, it is possible to simulate physical properties describing the state and behavior of entities. The solution for us will in future use the mixed reality and a digital twin concept to train the maintenance teams. Here in this paper, we shown the initial step of image acquirement and respective 3D reconstruction by a simulated operation. The next step is the implementation (through Blender, Polycam and Unity) using an AR/VR headset: initially Hololens 2 (Microsoft). The 3D reconstruction test we did aimed to understand the digitization process to insert it in a virtual environment (Blender, Unity, etc...) and to understand what functionalities Hololens 2 (for example) can offer. These next step will be focused on the visual part and on the virtual graphical environment, with the creation and implementation of the scenarios that will be used for training the company's employees. In parallel, we will carry out the analysis and studies to obtain the kinematics and risks of the real environment. We will also verify the possibility of including, in the virtual environment, the simulation of electromagnetic effects existing in the real environment.

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