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An as-built digital twin visualization and generation tool using with three-dimensional CAD models and 360º images of industrial facilities.

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Abstract. Today, many companies use digital twins as part of their activities. Digital 3D models enable planning, data extraction, simulations, and training on local conditions. However, an incorrect digital twin may induce errors that offset all possible advantages of the digitalization process. On the other hand, an information-rich digital twin allows simulations and data extraction to be faithful to reality. Enriching the data of a digital twin is a process that takes time, expert analysis, costs, and equipment, making the update process difficult. Photos, 360º images, and 3D models can be used to support evaluation and updates. However, differences between pictures and models yield confusion when transferring and connecting information. This work presents a tool that explores the benefits of combining 360º images of industrial facilities with three-dimensional CAD models to generate a correct as-built digital twin. This tool has an interface capable of displaying three-dimensional models of an industrial plant in conjunction with 360º photographs, allowing the user to navigate an augmented reality environment. GPS or simple annotations in the 360º images allow an easy manual camera calibration interactive process. The tool proposes an effective interaction to make annotations in the CAD models and the 360º photographs.

Keywords: Visualization, augmented reality, digital twin, three-dimensional models, annotation

1 Introduction

Currently, industries focused on improving their production processes, and the working conditions of their employees use industry 4.0 to help manage their facilities. The intelligent industry segment allowed companies to use virtualization, integration, analysis, and simulation as a positive factor to improve aspects such as optimizing processes, reducing costs, and increasing operational efficiencies [1].

One of the technologies used by Industry 4.0 is digital twins. Digital twins, as described by Grieves and Vickers [2], are a "set of virtual information constructs that fully describes a potential or actual physical manufactured product from the micro atomic level to the macro geometrical level. At its optimum, any information that could be obtained from inspecting a physically manufactured product can be obtained from its Digital Twin". Digital twins have wide usability and can be divided into segments like X modeling, data acquisition, data analysis, or information processing. Each segment can use different representations, such as 3D models, images, sensor data, and artificial intelligence [3].

One of the segments of digital twins is their visual models, and each model describes a geometric entity that faithfully represents its real version. In industry, 3D models are mainly used, in addition to having the ability to represent geometric shapes. It is also possible to associate them with other types of information such as sensor data, expert assessments, parts identification, or any information that may be pertinent to the actual data.

Industries that use digital twins can use their advantages such as remote installation monitoring, activity planning, evaluation, diagnostics, simulations, data extraction, automation, and other advantages [3]. However, these benefits are only reliable if the data extracted by the digital twin is in common with its real representation. A big challenge for digital twins is adapting to physical space's variability, uncertainty, and fuzziness. Another even more significant challenge is when inconsistencies between models and reality appear, as identifying and updating them requires much effort depending on what needs to be changed [4].

Enriching a digital twin with new data and updating it is hard because it involves using other media types, expert analysis, costs, and equipment. This work becomes even more complicated when industrial facilities are located in places of limited access, such as nuclear power plants, oil platforms, bridges, and skyscrapers. An alternative to sending a specialist to a risky location is to use resources that store information, such as videos, images, 360º images, and geolocation. However, the inconsistencies between the different media types still make transferring and connecting information difficult.

This work presents a tool that explores the benefits of combining 360º images of industrial facilities with three-dimensional CAD models to generate as-built digital twins. This tool proposes to create an augmented reality environment that allows the user to visualize three-dimensional models of an industry combined with 360º photographs. The main idea is to propose an interface that allows the user to navigate through the installations of a location and associate 360º images to certain positions in the scenario. Moreover, create annotations that may indicate inconsistencies both in the CAD model and the image to build a digital twin that is true to reality, "as-built."

2 Related Work

Pereira et al. [5] presents a virtual reality application for creating navigable scenery that uses 360º panoramas as a reference. The user can add different media types to the scene within this environment, such as images, videos, and texts. The presented methodology allows the user to navigate between different panoramas, and each panorama has an associated 3D model that represents the exact location. The user can place arbitrary information associated with scenario elements and display it from an HMD (Head-mounted Device).

Another application for visualizing digital twins from 3D models is the work done by Barboza et al. [6]. This work presents a simulation in a virtual reality environment of a Floating Production Storage and Offloading. During navigation, the user can identify parts of the 3D model and retrieve specific information about them. The user also has a visual tool to find the distance in meters from two points of interest.

On the other hand, Pessoa et al. [7], presented a tool that uses 360º panoramas to simulate an electric power substation. In each photo, experts mapped the essential equipment for the substation operation. During the simulation, the user can see the current status of each piece of equipment, including detailed information such as on or off status, equipment model, and whether an electric current is flowing, among other information.

Taneja et al. [8] presented a work aimed at finding problems of a digital twin of a city from panoramic images taken from Google Street View [9]. The software uses image geolocation to estimate the correct position of the image in the 3D model, then undergoes a correction algorithm to find the best possible fit between the two media. After the adjustment, it is possible to compare the digital twin and the panoramic image, in which the methodology suggests a metric that measures the error in the 3D model.

3 Proposed application

This section describes how the proposed application was architected. The nature of the data, the data extraction, and the steps necessary to create the digital twin are explained.

This application proposes building an augmented reality scenario that displays three-dimensional models and 360º images. The application has three significant steps: data pre-processing, responsible for retrieving information from the models and transforming the 3D models into a lighter representation for display; scenario generation, where the user can create or edit a scenario, apply minor corrections to the positioning of the images, navigate through the scenario and create annotations on the 3D model and 360º images; and digital twin modeling, responsible for creating a digital twin that includes scenario information and annotations later provided by the user. Figure 1 describes the required steps and their internal processes.

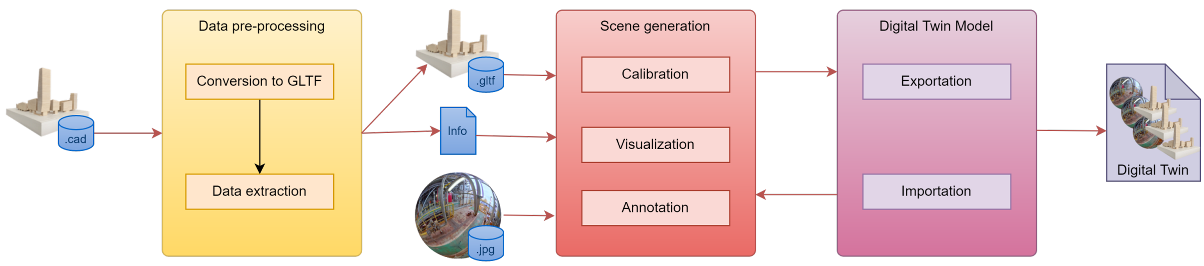

Figure 1. Application overview

3.1 Dataset and Data pre-processing

The application works with two types of data: three-dimensional CAD models, which represent the installation of an oil rig, and 360º photographs that employees captured during a site visit.

Each CAD model received represents the platform during the planning stage. The CAD model includes some information such as part identifiers, safety information, and other information. Each CAD model received represents the platform during the planning stage. The CAD model includes some information such as part identifiers, safety information, and other information. The CAD models were not built for display in conventional viewers and needed to be converted to a lighter and more compact format that could store the essential information of the model and its graphical information. The GLTF format [10], created by Khronos Group [10], was chosen because it can store information such as a hierarchy of nodes, cameras, lights, and materials. It is also possible to associate them with geometric information such as vertices, indexes, shaders, animations, and other graphics information [11]. Conversion to GLTF allows three-dimensional models to be displayed on a web page, the current application development environment. Figure 2 shows a part of the oil platform after the conversion.

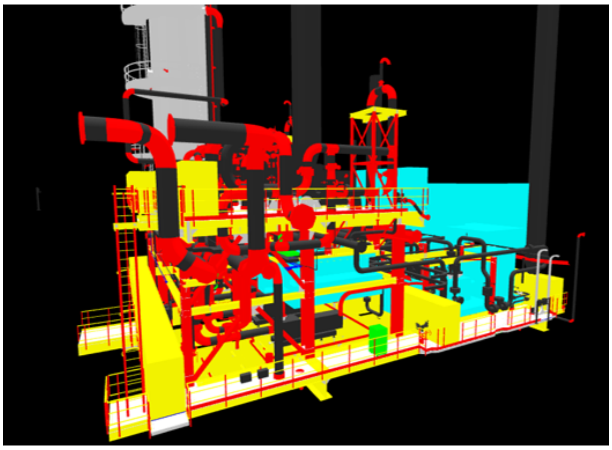

Figure 2. Three-dimensional model of some oil rig parts

In addition to converting the CAD model, information about each part included in the model is extracted and given a unique identifier. The application later uses the extracted information to help the user identify the components he selects during his interactions.

Another type of data used in the application is 360º photographs, as seen in figure 3. The images are composed of photographs of the employees' workplace, contain some geographic information, and present the actual conditions of the platform after its operation. An equirectangular panorama represents each photograph. To be imported, each image is treated with a spherical surface and distorted to map to a planar surface, i.e., the polar coordinates of the image are converted to planar coordinates [12].

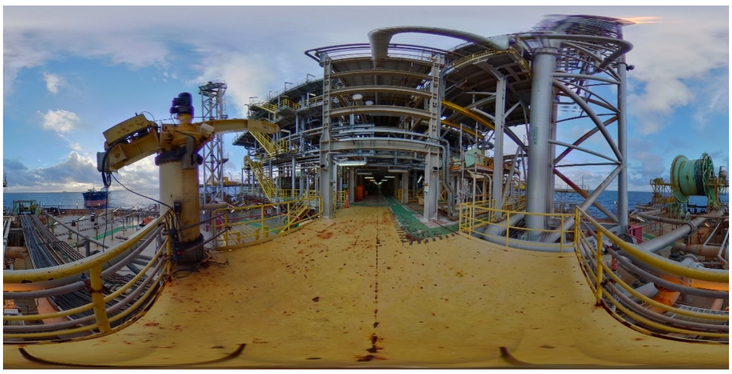

Figure 3. Panoramic image captured during the visit to the oil rig

3.2 Scene generation

A scenario is described as the combination of three-dimensional models with 360º images displayed together through an augmented reality environment. The user must build a scene using one or more available 3D models. These models represent one or more oil rig installations.

After choosing the models, the user must add a 360º image. Each image is treated as an individual camera using equirectangular projection [13]. The user can change its extrinsic values, i.e., the positioning of the projected image in relation to the three-dimensional model, and some of its intrinsic values to simulate camera conditions [14]. This calibration process is done manually by the user.

During the calibration process, the user has an interactive interface where he can navigate the scenarios to adjust the camera's positioning, and the user is allowed to add one or more cameras and control them independently. To facilitate the adjustment process, during navigation, the user can choose to control the opacity of the image. That is, they can view the 360º image and the 3D model together and project the image directly onto the model's texture, applying a projective texture [15].

With the scenario cameras calibrated, during the visualization, the user has the option of creating annotations that can indicate external variables, unmapped elements, pathologies, or any additional information. Three-dimensional models and 360º images are susceptible to receiving annotations from the application.

The user must select the piece of equipment of interest and add a comment to create annotations on the three-dimensional model. The informed text becomes associated with the object's unique identifier during this process. The user can draw shapes directly on the screen to create annotations on images. Each drawn shape is transformed into a 360º mask associated with the original image and can later be associated with some information.

3.3 Digital Twin Model

After creating the scenario, the application exports the digital twin with the adjustments made during the calibration and annotation step. This scenario can be sent to other users as long as they have access to the application.

The user can export the 3D models in GLTF format to support other viewers, with the added information in another separate file. The 360º images can also be exported, including the masks generated during the annotation process.

The digital twin model can be used with other Industry 4.0 applications. Every user-generated annotation is associated with a unique identifier of the three-dimensional model or a mask of a 360º image. These annotations are available to be exported from a JSON file.

4 Results

The implementation functionalities, such as manual calibration, visualization, and annotation, are shown below.

Figure 4 shows the camera calibration process. During calibration, the user can choose the camera positioning and change the Field of View.

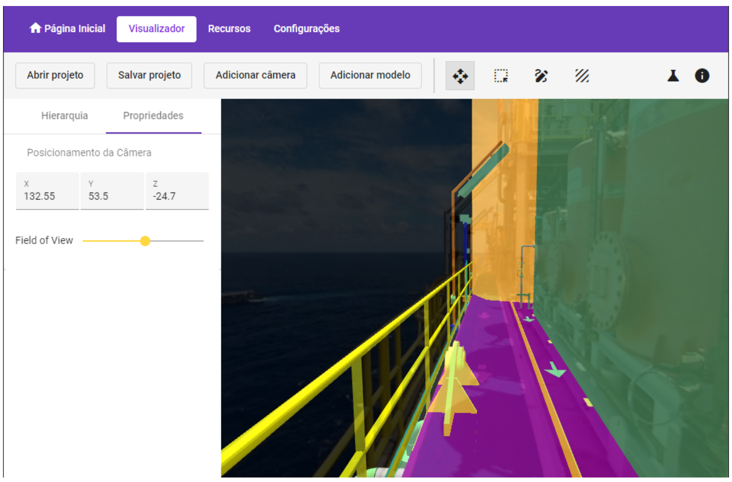

Figure 4. Camera calibration procedure. Extrinsic and intrinsic values can be edited on the left side of the interface.

Figure 5 presents viewing the three-dimensional models and the 360º images. The user can choose to use an alternate view between the 3D model and the image, in which he can change an opacity value that allows him to tell how opaque the image should be in the scene, or the user can opt for a view using projective texture, where the image is projected directly onto the model as if it were part of the model's texture.

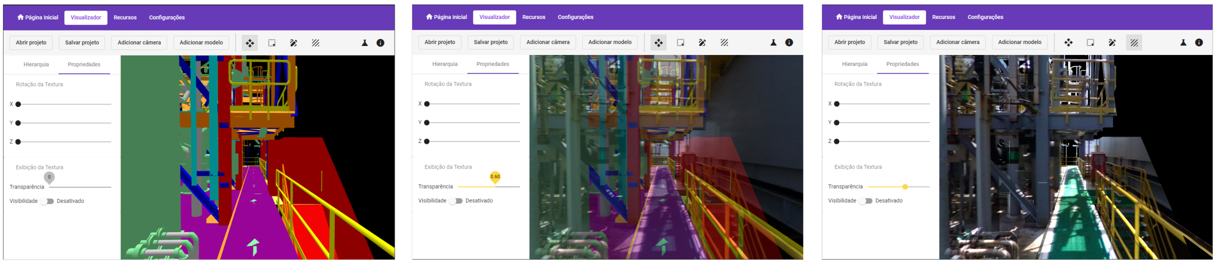

Figure 5. Scenario visualization types. From left to right: model only, model with 360º image, projective texture.

User-created annotations distinguish between three-dimensional models and 360º images. Figure 6, on the left, shows the process of creating an annotation of a part of the three-dimensional model. During this step, a text box for writing annotations is available, along with some information that identifies the selected part. On the right, it presents the creation of a 360º image mask. The user can make markings by creating drawings through the interface.

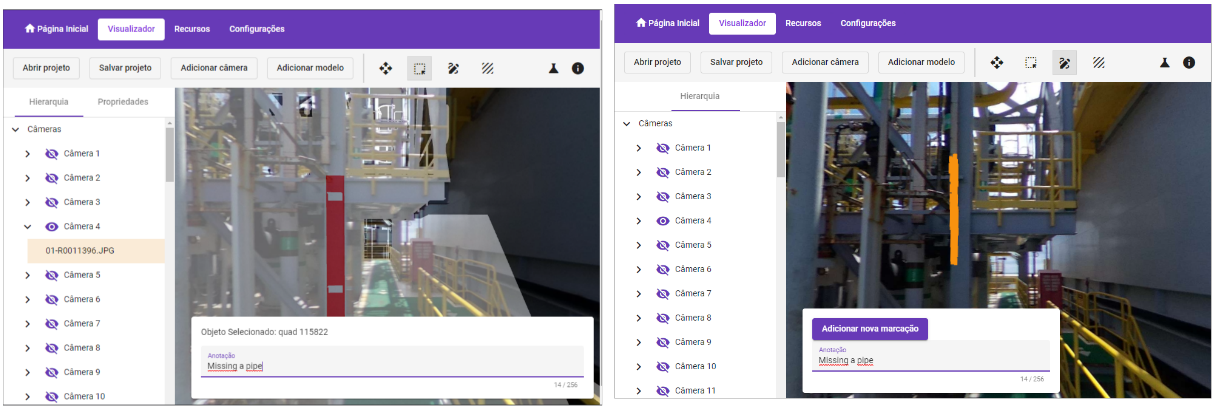

Figure 6. Annotation types. On the left, annotations on the 3D model; on the right, annotations on the image.

4.1 Use-cases

To better exemplify the use of the application, Figure 7 shows a case where the 360º images of the platform and its respective model are correctly positioned. From the application, it is possible to see that the digital model is not equal to reality because there are different equipment in different positions from the initial planning or errors during the construction of the CAD model.

Another example, artificial intelligence software focused on detecting rust on metallic structures was used in the 360º image of the site installations. Each possible rust region was marked on the image and turned into a mask.

Reading the images makes it possible to detect which parts were subject to rust corrosion. Figure 8 shows the masks being projected directly onto the model texture.

5 Conclusion

This work presented an application capable of simulating an augmented reality environment with three-dimensional models and 360º images to build digital twins. Due to the time differences between the generation of the three-dimensional model and the capture of photographs, several problems challenge the quality of the digital

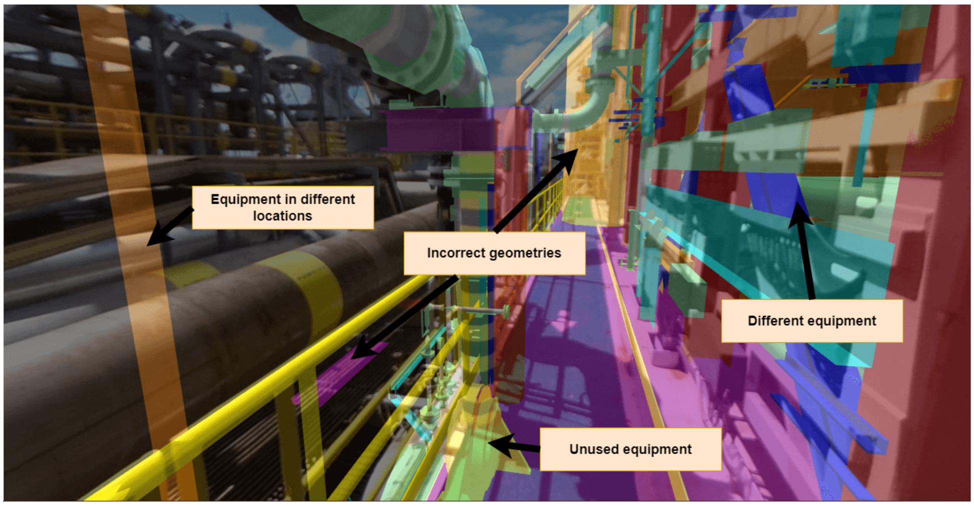

Figure 7. Error cases found comparing the panoramic image and the three-dimensional model.

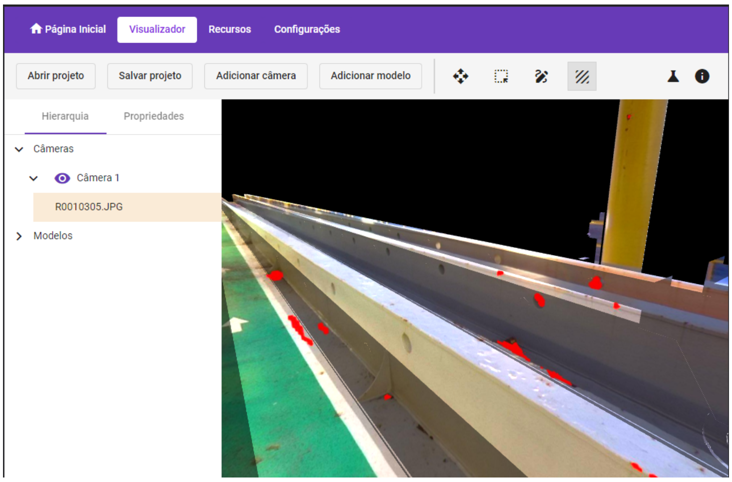

Figure 8. Demonstration of the corrosions detected in the structures together with the respective 3D model.

twin. However, this implementation presents an interactive interface that allows an expert to observe and identify differences between the different types of resources.

For the industry, this system allows experts to explore and evaluate real situations and create digital twins more faithful to the truth without needing additional costs and risks to their employees. In turn, a faithful digital twin enables the use of Industry 4.0 such as automation, simulation, data analysis, and other technologies.

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