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APPLICATION OF BIM AND AUGMENTED REALITY IN A HYDROPOWER PLANT MODERNIZATION

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ABSTRACT

This paper presents results of case study São SimãoHydropower Plant, the development and testing of an application that applies augmented reality to display BIM information over the real infrastructure of hydropower plant existing areas. The application aims to assist users in identifying interferences between future AEC projects and current electrical, mechanical and civil infrastructure. The work focused in evaluating BIM data and sources to face data integration issues with an Augmented Reality development platform and in combining multiple tracking strategies to achieve assertive positioning of objects in the real world. It took several iterations to meet precision goals and establish a logical sequence for the algorithm. This tool intends to reduce rework and losses in construction sites by sharing project information and assisting decision making process.

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INTRODUCTION

Architecture, Engineering and Construction (AEC) sector has always applied 2D representation as reference for construction planning. With technology advancement, orthogonal projections started to be created by stitching different perspectives and forming 3D visualization (SINGH, SUNTHARM DELHI, 2020). Building Information Modelling(BIM) technology was incorporated to projects, serving as the only source of data for different stakeholders, allowing task simplification and facilitating resources estimates, interference identification, progress monitoring and asset management (SING, DEKHI, 2019). Although BIM technology allows for better comprehension of AEC projects lifecycle and is increasingly present in several countries (HAJJI *et al*., 2021), integrating digital images to the real world would collaborate for a better comprehension of future projects and structures interactions with real entities (WANG *et al*., 2021). Improvements for BIM application have been conducted to apply Augmented and Virtual Reality to project 3D models and data over the real structure and/or environment. Augmented Reality (AR) improves workflows and data access on field by exploring 3D models associated with BIM semantical information (LINHARES, GROETELAARS, 2021). Hugo Silva, Gaber and Dolenc (2021) described three main use cases of AR and BIM integration in AEC workflows: (a) project planning with 3D projected models to evaluate changes; (b) project execution for monitoring and comparing deployment; (c) project delivery for auditing results. Authors have classified AR BIM applications considering different perspectives. Chai *et al*. (2019) described three forms of interoperability between BIM and AR. First, projections over the table to present de 3D project of a 2D blueprint. Second, on-site projections of 3D models over the real world. Third, remote monitoring of field by video streaming, which are further augmented as a form of auditing. Conversely, Linhares and Groetelaars (2021) classify applications and software by its capabilities such geometrical model visualization, semantical data availability, data and model manipulation, model/environment editing and cloud collaboration. BIM and AR are both research fields with wide range of works still in development duo to the complexity of interoperability of data and technology maturity. From a business perspective both technology faces skepticism duo to costs, user comprehension (SARNOT, 2021), hardware limitations and AEC dynamics (HAJJIetal., 2021). BIM and AR interoperability face challenges regarding data management, mobile devices present limitations being capable of displaying models with maximum of 100mb and less than 1 million surfaces (ARAÚJO, 2018). Several projects lack the semantical data (LINHARES, GROETELAARS, 2021) or have data lost when the 3D model is converted to another file format. AEC sectors dynamic frequently fragments projects, the supply chain is highly fragmented with participation of both large companies and varied groups of small suppliers (HAJJI*et al*., 2021) resulting in diverse data standards. The Industry Foundation Class (IFC) standard was created and certified to ensure compatibility for BIM data sharing(BORR *et al*., 2018). According to a survey conducted by SEBRAE (2021), the Brazilian Micro and Small Business Support Service, at least 20 software that applies BIM technology are available for application in at least one stage of a AEC project lifecycle and 150 of them are IFC certified. Despite applying IFC standard, the data conversion and exporting is accomplished by different suppliers, occasionally causing incompatibilities (PASDIORA, 2021). Conversions may cause data losses, model distortion and change on file sizes (MEŽA, TURK, DOLENC, 2014), demanding additional interactions to address incompatibilities. AR development is frequently based on game engines which are not fully compatible or incompatible with IFC files, representing an additional challenge to this work. In this paper, we developed a case study (São Simão Hydropower Plant) toevaluate a solution that projects BIM data in AR to assist in identifying interferences in a hydroelectric power plant modernization project. We addressed the challenge by identifying the most compatible process to access, adapt and display BIM data in real world in the context of the project.

METHODOLOGY

Case Study: São simão hydropower plant: São Simão Hydropower Plant (Brazil) operates with 6 turbines and generates 1.710 MW.The operationsstarted in 1978 and the plant will be upgraded in the next seven years. This modernization process motivated the development of an AR solution capable of projecting BIM data over the existing physical structure. By visualizing both digital and real information at the same time, the user may identify interferences between current and future civil, electrical and/or mechanical structures. The challenge faced by the hydropower plant is modernizing the structure while it continuously operates and needs to meet regulated generation goals. In this scenario, the application will assist the Health, Safety and Environment team on making decisions based on information to isolate areas when deploying structures by accessing available information about project on the field. The proposed approach applies the combination of AR technologies to project 3D objects over real world surfaces and re-position the object precisely at its future location (Figure 1), which will assist in decision making process and project adjustments. We achieved this goal by dividing the methodology in three steps. First, we evaluated BIM data and sources, file formats and sizes, 3D model polygons, meta data available and compatibility with development platforms and devices. Both proprietary formats, such as NWD, and open formats (IFC) were tested. The project was developed in Unity, a suitable platform to create AR experiences. By default, Unity is not compatible with BIM data and standard AEC software formats, requiring a specific solution to access and import the available data. The multiple data sources, incompatible file formats and high polygons model was one of the main challenges addressed at this phase, which took several interactions to evaluate imported data and models and the application of multiple tools and strategies. Then, we evaluated different AR capabilities and SDKs to design the application behavior. AR capabilities tested were image tracking, plane tracking and cloud point. SDKs tested were AR Foundation with ARCore, Vuforia, Wikitude and EasyAR.The main metrics applied to evaluate testes results were tracking capabilities, anchoring objects and drifting results. We also considered SDK costs as variable to evaluate limited availability of each kit for the project purpose. As afinal step, we tested the application with 3D models of electrical and mechanical structures in real locations to evaluate the application precision, which lead to rework interactions to correct AR strategies. We conducted three pilot testing events at the Hydropower Plant and revised AR strategies and SDKs to improve 3D model projections.

Figure 1. AR concept

RESULTS

Bim Data and Sources: By developing the AR solution, we faced several challenges related to interoperability and data compatibility. Throughout the project, we identified that multiple suppliers designed the digital structures. Multiple AEC software, both proprietary and open, were used to create BIM information.We created three strategies to evaluate the acquiring data process and define the most suitable solution for the project. As we identified multiple sources of data, the first strategy consisted of exporting IFC files and importing data with a third-party plugin compatible with 2x3 and 4 IFC versions. For different files, we experienced different results. IFC files generated by specific software were not imported. Results shows that proprietary and open AEC software often make IFC exporters available. However, interoperability was not guaranteed. We also tested exporting Unity compatible format directly from the AEC software. Most tools are capable of exporting FBX file, which is fully compatible with Unity.

Although, this process also faces some challenges. Exporting process took a lot of time and resources and often resulted in failing due to computational requirements. The BIM meta data is lost in the process. The FBX file supports only the 3D Model information. The third strategy consisted of working with the federated BIM model, trying to avoid data distortion and losses. The federated model consisted of a NWD file that puts together all the BIM projects and is managed it the proprietary software Navisworks Manage. We imported the files by using a Unity proprietary product. PiXYZ Studio, which is compatible with several AEC industry standards. We achieved the best results with this strategy. At the same time, it is the costliest of the presented approaches. Table 1 summarizes the BIM data and sources evaluation results.

Table1. Data and Sources Evaluation

File Type	IFC	FBX	NWD
Unity Importing Success Rate	60%	100%	100%
3D Model Availability	X	X	X
Meta Data Availability	X		X
No Cost Solution		X	
High computational requirement process		X	X

We also need to manage the imported files, most of the 3D models presented a high level of detail and polygons that exceeded the mobile device AR limits and capabilities. The AR application content had to be simplified, as shown in Table 2. Besides the level of detail adjustment, we also had to divide the areas when displaying content in the application to reduce the device overload and to restraint information to the visible area.

Table 2. 3D Model Sizes

Level of Detail (Total of Triangles)	Original Data	Simplified Data
Electrical Gallery	683.000	99.700
Mechanical Gallery	5.700.000	1.900.000

AR Capabilities: We have tested multiple AR SDKs and different AR tracking capabilities to define the most precise solution for BIM projection on top of the real-world structures. We started by testing SDK features capable of extending tracking to large areas. Since the Hydropower Plant is composed of large segments with more than 10 square-meters. The proposed solution also allowed movement of the user through the large areas, avoiding tracking losses and driftingobjects or changing positions significantly, which would prevent the capability of comparing 3D projects with real world structures. The tests resulted in a qualitative analysis, which allowed us to prioritize SDKs and AR capabilities. Table 3 summarizes the results and the key capabilities we have evaluated.

Table 3. AR SDK Tests

AR SDK - Feature	Tracking	Drifting	Cost
EasyAR–Point Cloud	Good	Low	Low
Vuforia - GroundPlane	Excellent	Low	High
Wikitude 9 – Extend Tracking	Good	Medium	High
AR Foundation / ARCore – Plane Tracking	Excellent	Low	Free

Based on performance and cost evaluation, we tested two different techniques of AR tracking: Point Cloud and Plane Tracking. Point cloud applies SLAM algorithms to find a point in real world defined by their distance and coordinates related to device position. This strategy demands scanning the environment before starting an AR experience. Plane tracking algorithms automatically apply SLAM to detect horizontal plane surfaces in real world to trigger augmentations. Both techniques had the object of triggering digital object projections on top of real world with position accuracy. Although the strategy successfully anchored objects in real world, it lacked a reference to position the object in the effectively desired position. We solved this issue by using image tracking for repositioning the object, which is triggered only when a tag image is visualized by the camera. Figure 2 presents the logical sequence of positioning the AR object in the precise and expected location.

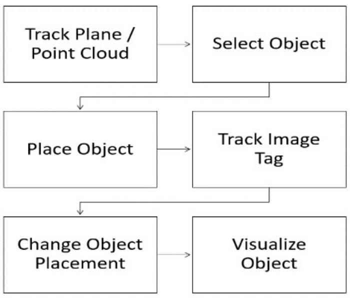

Figure 2. Positioning Logical Sequence

Figure 3 shows the type of image tag the solution applies for repositioning objects and the AR recognition triggering in the device.

Figure 3. Image Tracking

The first test was performed in one of the main transformers ofthe Hydropower Plant, applying the point cloud technique. The test starts by scanning the main transformer area to collect the data to serve as reference for the positioning algorithm. Then, we began tracking the world and trigger the AR by pointing at the image tag. In this test we noticed that the point cloud is highly stable in anchoring the objects in real world. However, we had difficulty toposition objects in the desired location. Most of our tests resulted in 3D objects placed a dozen of centimeters in front of the designated position. Figure 4 presents an AR 3D object positioning with point cloud. The real object position demonstrates the difference between the desired and effected position.

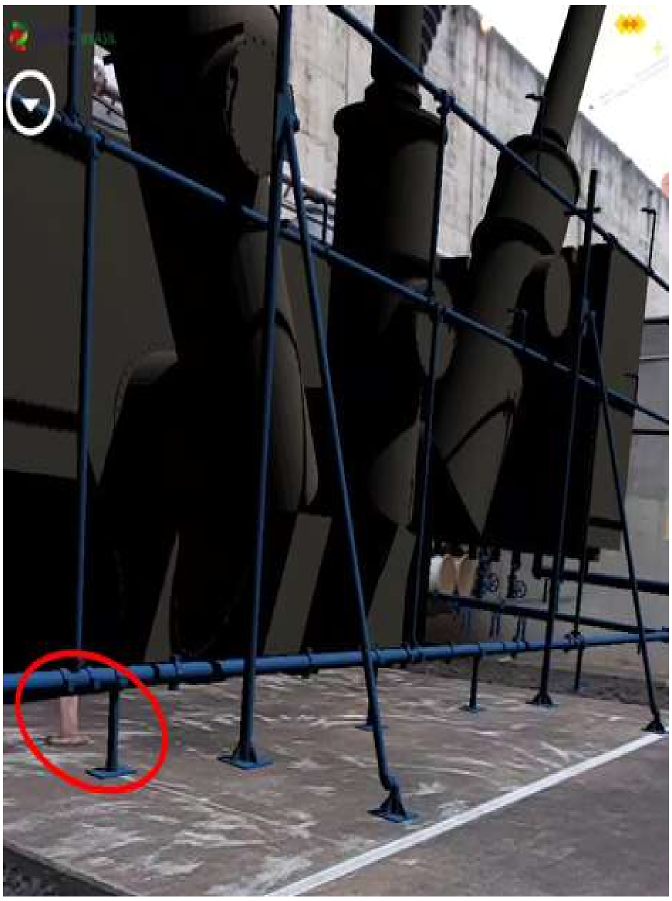

Figure 4. Point Cloud Test

The conclusion is that the position of objects is affected by the scanned area. As the studied area presents electrical hazards it was not feasible to accurately scan and position the object, demonstrating a limitation of the technique for the proposed work. The Hydropower Plant is an existing infrastructure demanding the solution to adapt to project future structures in scenarios where the space is already occupied by current real objects. The plane tracking method differs from point cloud by tracking surfaces. We substituted the initial method and applied the same logical sequence shown on Figure 2, expecting that using the ground as a reference would not result in depth distortion by existing objects. Field tests demonstrated an improvement in objects positioning. At the same time, tracking stability was sustained. Despite the noticed enhancement, positioning test shows a couple of centimeters of difference between real and digital information, as shown in Figure 5.

Figure 5. Plane Tracking Test

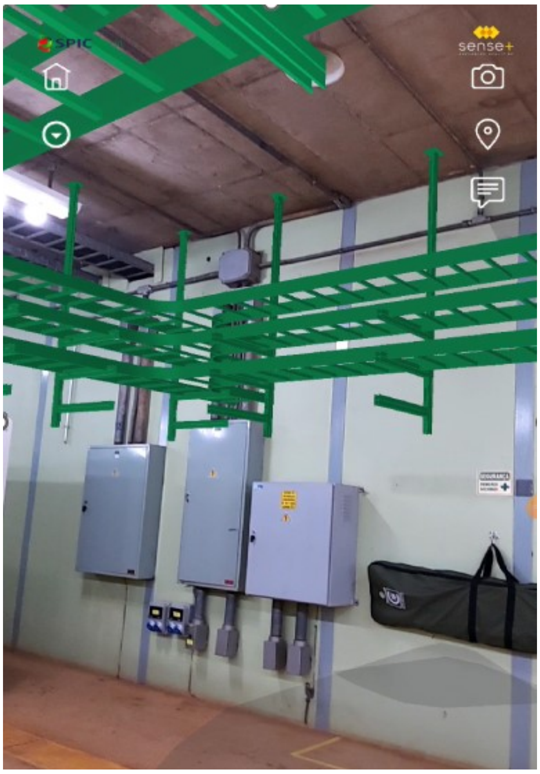

Figure 6. Plane Tracking Test

Analysis suggest that several factors need to be evaluated to identify the reason behind the offsetting of the digital layer. Main hypotheses include 3D model distortion originated by file conversion, accuracy of the physical tag positioning and device performance. We identified a performance drop in devices with 4 GB RAM. Measures indicated an FPS drop and delay in display. Plane tracking solved depth issues, but in exchange objects located on the ceiling suffers from a couple of flickering performance. As the ground is the algorithm reference and anchor, depending on the velocity of movement, tracking may be lost. Yet this behavior rarely occurred during the tests. Figure 6 shows the projection of digital cable trays.

CONCLUSIONS

This paper presented results of case study São SimãoHydropower Plant, the development and testing of an application that applies augmented reality to display BIM information over the real infrastructure of hydropower plant existing areas. The application aims to assist users in identifying interferences between future AEC projects and current electrical, mechanical and civil infrastructure. This tool intends to reduce rework and losses in construction sites. Project results showedthe issues behind BIM data availability and compatibility. The existence of several suppliers that apply different AEC software. Although IFC exportation is available, not every exported data is successfully converted and imported. Distortion of 3D models and high polygons quantity need to be addressed for mobile devices applications. We also tested AR techniques defining that the most suitable strategy for the project was to combine plane and image tracking to accurately position 3D information. Point cloud presented satisfactory results but lacked precision in an environment with a considerable amount of real objects. Future advance could explore several issues related to projection accuracy and data compatibility. We had to create a specific process to extract and adjust BIM data for the proposed use that take several steps to acquire the data and a high-cost alternative to adapt 3D models to low polygons limits. Other AR strategies could be explored to reach a more accurate positioning of the 3D objects. Object recognition and Artificial Intelligence algorithms that use real objects as a reference could achieve these results by registering content over the already built physical structures.

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