# Contextualizing Data with ProxSituated Virtual Environments: From Flood Risk to Dam Monitoring

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***Abstract*—ProxSituated analytics environments use proxy representations of referents instead of the actual physical objects of analysis for data representation. They can be used to complement or replace conventional situated analytics processes in situations where the latter are not practical. We describe two applications of proxsituated virtual data analysis environments to the Civil Engineering field. The first, *FloodVR*, is targeted at analyzing flood impact data overlaid on the affected terrain. The second, *GalleriesVR*, is designed for visualizing the impact of seismic events on dam structures. These applications allow engineers to analyze data contextualized with its respective objects of analysis without requiring them to be on-site. They also offer exocentric points of view, which would be unattainable with conventional/immediate situated analysis.**

***Index Terms*—proxsituated visualization, virtual reality, immersive analytics, flood risk, dam safety control**

## I. Introduction

Proxy of situated (commonly designated 'proxsituated') analysis environments differ from conventional/immediate situated analysis processes because they use a representation of the physical referent instead of the actual object of analysis [1]. Proxsituated environments offer the possibility of *off-site* scientific visualization without the need to be *in-situ* for contextualizing data with the referent.

While nothing provides a more accurate spatial awareness of a structures' physical features than standing in front of the actual structure, such a scenario is frequently impractical. Engineering structures are often located in remote locations, and their analysis is often carried out *off-site*, in the office, and not in the field. Regardless, one could argue that, while looking at the data without contextualizing it with the structure is not ideal, looking at the real structure without contextualizing it with the data is equally problematic in an analysis scenario [2].

In this work, we describe the functionalities of two work-in-progress prototypes aimed at proxsituated visualization of engineering datasets. While formal user studies are planned for the near future, we still lack conclusive results apart from user feedback from preliminary testing. As such, in this work, we focus mainly on the description of the objectives and features of the two prototypes as well as the reasoning behind their development.

Work supported by national funds through Fundação para a Ciência e a Tecnologia, I.P. (FCT) under projects UID/50021/2025 and UID/PRR/50021/2025, PTDC/ECI-EGC/5332/2020 and under grant 2021.07266.BD. It also had the support of the UNESCO Chair on AI & VR.

## II. Related Work

The use of proxsituated analytics environments for visualizing contextualized engineering datasets has been addressed in previous scientific works. In the scope of building facade durability, Nouri *et al*. [3] used proxsituated environments for representing time-dependent material degradation datasets, overlaid to virtual building representations. Cornel *et al*. [4] proposed the use of proxsituated environments for large-scale visualization of flood impact at local and regional scopes.

In the field of dam safety control, Verdelho Trindade *et al*. [5], [6] initially used immediate situated environments for enabling contextualized *on-site* analysis. They used augmented reality (AR) to superimpose structural displacement information on dam structures. Later, they transitioned to proxsituated analysis [2], [7], using virtual reality (VR) and realistic representations of dams instead of the actual structures.

## III. Flood data visualization

Dams are fundamental infrastructures for maintaining the hydrological balance at local and regional levels. They can efficiently regulate the volume of water that flows between hydrological basins, making them fundamental instruments in the prevention and attenuation of floods. Within this scope, a key task of dam safety control is to assess the impact of the dam operation on the downstream populations. Flood prediction models, simulation, and visualization tools are crucial for that purpose.

In this context, *FloodVR* [8] was implemented as a *proxsituated* application for visualizing the impact of floods resulting from dam peak discharges (Figure 1 left). The application allows users to fly above flooding-prone terrain located downstream of dams and visualize which areas pose the greatest risk of flooding. It also enables the visualization of the impact of floods on individual buildings in urban areas.

We used as a case study the hydrological system downstream of the *Cabril Dam*, in the *Zêzere River*, Portugal. Within this system, users can regulate the water levels of different reservoirs: the upstream reservoir of the *Cabril Dam*, the upstream reservoir of the *Bouçã Dam*, and the reservoir in which the village of *Dornes* is located.

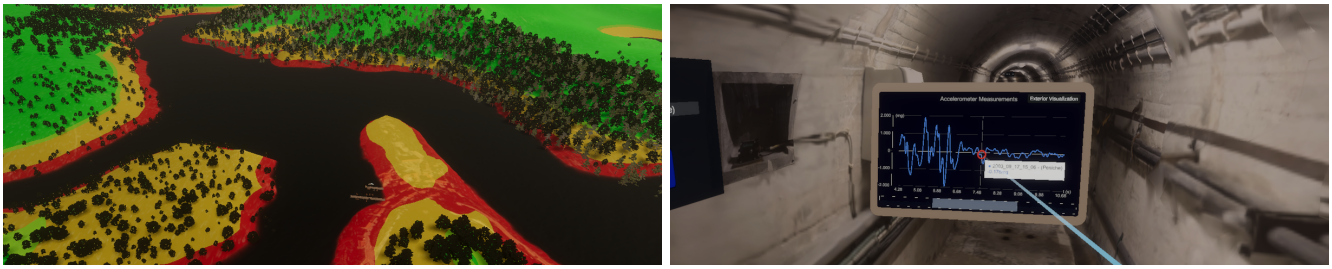

Fig. 1. Virtual proxsituated environments for flood risk (left) (Pinto 2024) and seismic impact data visualization (right) (Soares 2024).

The application allows users to toggle between the representation of flood risk heatmaps overlaid on the terrain and the simulation of urban flooding. For achieving the dynamics of the latter, we implemented procedural generation of different building layouts based on the actual positioning and volumetry of each individual structure in the village of *Dornes*. Terrain and building heights are computed together with the water level to determine the submersion percentage of each building. The colors of each building are then dynamically changed according to this submersion percentage.

## IV. Exploration of dam galleries

As we have seen in Section II, Verdelho Trindade *et al.* [2], [5]–[7] focused mainly on data analysis conducted from the exterior of dam structures. However, a very relevant activity in dam safety control is inspecting dams from their interiors. For this purpose, inspectors use maintenance galleries situated within the interior of dam cores that traverse the structures. From there, they can verify the integrity of the installed instrumentation, including the structural sensor networks (among other tasks, like detecting signs of pathology at the dam concrete core).

In this context, we set to develop *GalleriesVR* [9], a *proxsituated* application for exploring and analyzing structural data from the interior of dam galleries (Figure 1 right). We wanted to understand the challenges and possibilities of analyzing structural information contextualized by the proximity of the sensors that registered the data. We focused on a particular type of sensor, the accelerometer, used to register accelerations in the structure arising from dynamic phenomena such as seismic activity.

The *GalleriesVR* application allows users to move through the galleries, select a specific accelerometer, and visualize the accelerogram for that sensor corresponding to a seismic/dynamic event that occurred on a certain date. We again decided to use the *Cabril Dam* as a case study for this application and structural time-dependent datasets of accelerograms obtained from accelerations registered in this structure. The charts can be panned and zoomed using the controllers.

## V. Conclusion

In this work, we introduced two prototype applications aimed at better contextualizing engineering data with the object being analyzed. With that objective, we coupled immersive environments with realistic 3D models of the physical referents, as an alternative to using conventional 2D desktop solutions or AR on-site situated visualization. Such an alternative has the potential advantage of providing engineers and technicians with an off-site, immersive, and contextualized analysis environment, which reduces the need for *on-site*, immediate, situated visualization. This proxsituated solution also offers other relevant advantages, such as the possibility of exocentric visualization of the engineering structure being analyzed, a possibility that is not possible with purely immediate situated systems. Although formal user studies have not been conducted to obtain conclusive results regarding the user experience and performance of the prototypes, they are planned for the near future. Nevertheless, user feedback from preliminary testing is promising.

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