Lecture Notes
in Geoinformation and Cartography

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Paolo Fogliaroni
Andrea Ballatore
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Proceedings of Workshops and Posters at the 13th International Conference on Spatial Information Theory (COSIT 2017)

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Immersive Technologies and Experiences for Archaeological Site Exploration and Analysis

Jan Oliver Wallgrün, Jiawei Huang, Jiayan Zhao, Claire Ebert, Paul Roddy, Jaime Awe, Tim Murtha and Alexander Klippel

Abstract Immersive technologies have the potential to significantly improve and disruptively change the future of education and research. The representational opportunities and characteristics of immersive technologies are so unique that only the recent development in mass access fostered by heavy industry investments will allow for a large-scale assessment of the prospects. To further our understanding, this paper describes a project that aims at creating a comprehensive suite of immersive applications for archeological sites, including 360° immersive tours, skywalks, and self-guided explorations for education, and immersive workbenches for researchers.

Keywords Virtual reality · Augmented reality · Cultural heritage · Linked data · Spatio-temporal modeling

1 Introduction

Immersive technologies are becoming a tool of mass communication and as such offer the potential to disrupt education and research in the spatial sciences and beyond. This paper describes an ongoing project that has the goal of creating immersive VR (iVR) experiences of archeological sites for both educational and research purposes. The project focuses on the ancient Maya site Cahal Pech located in Belize. It combines environmentally sensed data, 360° video and photography, and manually created 3D models. Additionally, interactions are being implemented to virtually navigate the site and link additional media resources to create a comprehen-

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sive immersive experience for different VR setups: HTC Vive, mobile VR solutions, and augmented reality (AR). Intended applications for education are virtual field trips which allow students to experience and learn about the site in a more effective and realistic way compared to classic media. For scientists, digital workbenches will allow analyses and investigations with 3D models and associated data sources while being immersed in the site. We discuss the background of this project (Sect. 2), our data capture methods and content creation approaches (Sect. 3) as well as first prototypes for both educational and scientific iVR applications (Sect. 4). We also describe our plans for an underlying linked data based information system that stores all the heterogeneous spatio-temporal data about the site in a way that is suitable to drive the different applications and use cases (Sect. 5).

2 Background

Cahal Pech is located in the Belize Valley of the west-central portion of Belize on top of a natural limestone escarpment. Archeological investigations at Cahal Pech have been ongoing since the late 1980s. Excavations conducted in the site core in Plaza B identified contexts representing the earliest permanent settlement at Cahal Pech dating to 1200–900 BC. By the Classic Period (AD 300–900), the presence of temple pyramids, stone monuments, and the elaborate royal burials identify Cahal Pech as the seat of an important regional kingdom governed by a dynastic lineage (Awe et al. 2016). The monumental center at Cahal Pech is composed of at least 34 buildings (Fig. 1a), the largest of which, Structure B1 (Fig. 1b), is approximately 24 m tall. Plaza B is the largest plaza at the site, measuring approximately 50×30 m, and is bounded to the east by a triadic temple group.

Immersive technologies, as an interactive communication medium, are seeing a resurgence in popularity thanks to massively improved and more cost-effective products. The spectrum of immersive technologies has been described with different terms including mixed reality as a summary concept with AR at one end of the spectrum and VR at the other (Milgram and Kishino 1994). Here we use xR to refer

Fig. 1 **a** Map of the Cahal Pech archeological site. **b** Structure B1 and east side of Plaza B. **c** SfM 3D model of Mayan Sauna at Cahal Pech

to the vast spectrum of technologies that are becoming available. On the scientific side, xR research and visual analytics share a common interest in creating intuitive interfaces and digital immersive analytics workbenches (Simpson et al. 2016). xR technologies similarly take advantage of our innate understanding of physical reality within software environments (Bowman and McMahan 2007) and have proven to be very useful in visualizing spatial data in practice (Donalek et al. 2014).

3 Data Capture and Modeling

Developments in xR are accompanied by unprecedented advancements in environmental sensing and modeling technologies. In the following, we describe current approaches at our field site Cahal Pech.

Structure from Motion (SfM): 3D archeology is not new. Using image-based modeling, or Structure-from-Motion (SfM), to build photorealistic 3D models is, however, a more recent development (e.g., López et al. 2016). SfM can be applied to constructing models of large areas such as entire archeological sites, but also to create 3D models of smaller objects, such as individual artifacts. In our project, we have been using Agisoft PhotoScan Pro. Figure 1c shows a 3D model of a Mayan Sauna at Cahal Pech.

360° Photography and Videography: Photos taken by 360° cameras allow users to immerse themselves in a scene. We are using high resolution still imagery (Panono camera with 108 MP), 4K video (Nikon KeyMission), as well as flexible viewpoints using mega-tripods.

3D Modeling: Classic manual 3D modeling plays an important role for archeology in general and in the context of this work. The availability of such manually created models opens up the possibility for educational and scientific iVR applications to incorporate a temporal dimension in the form of interactive timelines or animations. We are using SketchUp for hands on modeling. In the addition, we plan to also make use of LiDAR data of terrain and objects to feed into the 3D modeling process.

4 Immersive VR Experiences and Research Tools

4.1 iVR Field Trip Experiences

Empirical studies have shown the potential of iVR in the teaching-learning process (e.g., Barilli et al. 2011). One of the biggest advantage of iVR for learning is that it affords learners a direct feeling of objects and events even if they are in the past, future, or imaginary. We briefly describe first prototypes of educational iVR experi-

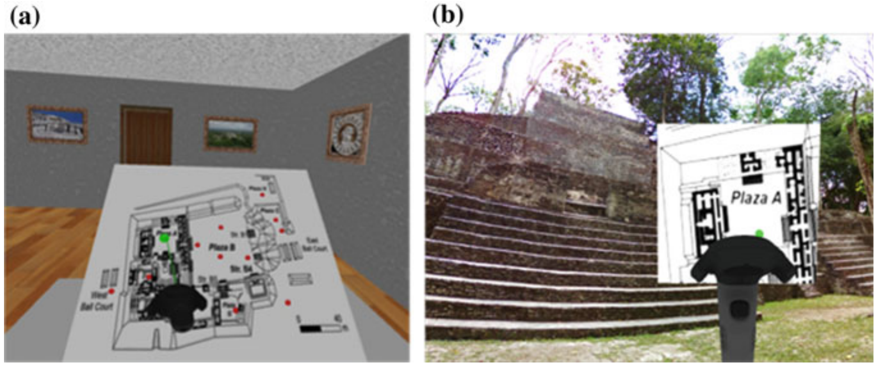

Fig. 2 **a** Overview perspective showing a map in a museum room. Users can point the laser emitted by the controller at a map point to view a 360° photo or select a path for a 360° video. **b** Image perspective with zoom-in map and current position indicated as a *green point*

ences created for the HTC Vive and Android-based mobile phones, all developed in Unity3D.

4.1.1 HTC Vive Experience

We are using the HTC Vive as it allows for room-scale experiences. Users can physically walk around, perceive the simulated space using a 1:1 body scale, and interact with digital content to extract, for example, geometric data from the visualization of realistic models. Figure 2a shows how users select a point or path on the map to immerse themselves in 360° scenes. A minimized overview map is attached to the controller for navigation purposes. The user's current position and visited places are marked in different colors to foster spatial awareness. A zoom-in map is attached to the backside of the overview map displaying the user's current position as a static or animated (in the case of a 360° video) point (Fig. 2b). Users can also navigate between different images or go back to the overview map to select other points.

4.1.2 Mobile VR Experience

The mobile version of our iVR experience is shown in Fig. 3a. Only the orientation of the display can be tracked based on the phone's accelerometer, screen space is limited, and no controller is available. Gaze control based on a reticle placed in the center of the screen is the main technique used to realize interactivity. The reticle will grow when placed on an element that can be clicked with the only button available by typical devices such as the Google Cardboard. In the image view, most of the interaction is realized via a simple popup menu that is also gaze-controlled.

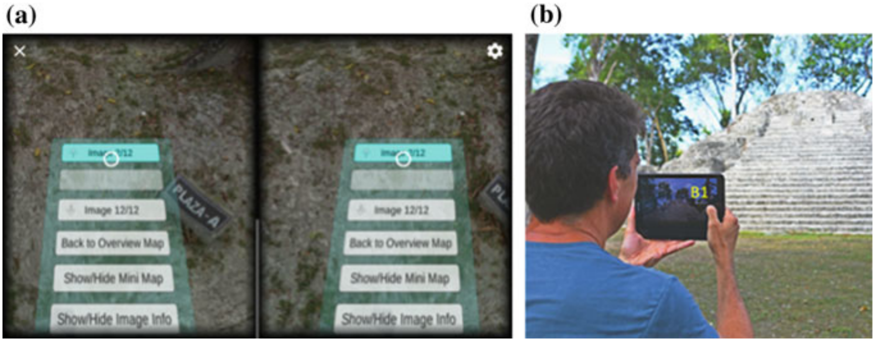

Fig. 3 **a** Image perspective with gaze-controlled navigation menu. **b** A simple AR application displaying additional information about buildings at Cahal Pech

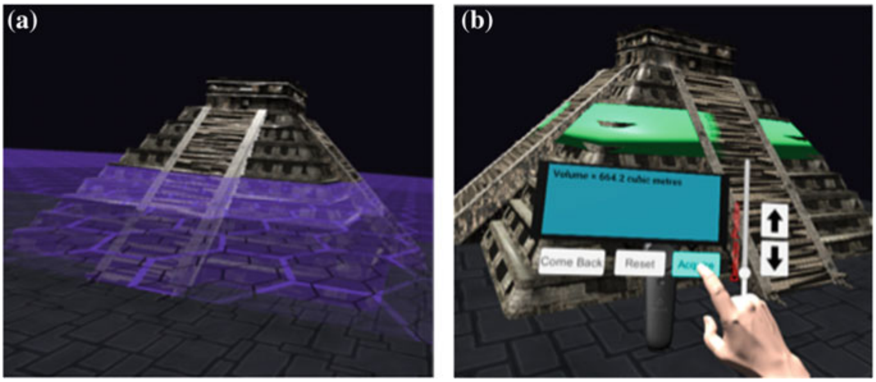

Fig. 4 *Top* and *bottom* faces of the volume detector cut the temple into three parts (**a**). A mesh is constructed along the surface of the middle part of the temple between two cross sections (**b**)

4.2 iVR Digital Workbench for Researchers

We are developing a digital workbench to provide archeologists with an immersive experience with information retrieval functionality and different measuring and interaction tools. One of the available tools displays general information of the site and allows for model manipulations such as vertical positioning, rotating, and scaling. Three other tools are available for measuring distances, areas, and volumes. Figure 4 illustrates interface and application to measure the volume of some part of a temple. More tools are currently under development and will be added to the workbench. We expect that some of them will find their way into the educational iVR applications as well to support exploration and experimentation.

4.3 AR Applications

In addition to creating iVR applications, the same approach and input data can be used to realize AR applications to improve on-site experience by providing complementary information about environmental features, buildings, or artifacts, or by even changing buildings. Manually created models for past times can be superimposed to create vivid animations of the historic developments of an area over time. We are just starting to tap the potential of AR for archeology and cultural heritage. A first prototype of an AR application is shown in Fig. 3b: Information about names of buildings are displayed when the building is looked at by the tablet's camera.

5 Sketch of an Underlying Site Information System

Creating and updating xR experiences described above currently requires substantial amounts of work. For the case of a xR visual analytics workbench for researchers, flexibility is required to allow for exploring all individual data, configure how objects and data are displayed, and modify the data if needed. We are therefore aiming for a more flexible approach in which archeological xR experiences and workbench for researchers are based on a central information system containing all data, media, and additional information regarding the particular site (see Luczfalvy et al. 2016 for the general idea of an archeological information system). This information system needs to support queries that can be spatial, temporal, and semantic at the same time. Table 1 lists a few use cases for querying the information system using natural language examples.

Table 1 Exemplary queries to the information system

Query	Modality
Provide all **360° Images** taken on *Plaza B*	Semantic + spatial
Provide all **Aerial Imagery** taken after *Jan 1, 2015*	Semantic + temporal
Provide all **3D Models** of **Historic Artifacts** found within 100 m of *Cahal Pech* that are from the *Postclassic Period*	Semantic + spatial + temporal
Provide a linked data graph view of *Artifact ID23415* with all **Media Sources** directly linked to it	Semantic, RDF

In the following, we briefly discuss the main components of the central information system we are envisioning, consisting of a central linked data storage with associated ontology, semantic-spatial-temporal query interface, VR experience generation software, and VR interface to the stored linked data. We also list challenges for which solutions need to be found when realizing the different components.

Central linked data storage: To support the automatic creation of VR experiences for education and research, the information in the information system needs to be heterogeneous (including sensor data, imagery, vector GIS data, archeological objects, general historic background information, external literature and media resources), multi-dimensional, and related to particular times and locations in space. In addition, as the query examples from Table 1 show, being able to access the data via complex mixed semantic-spatial-temporal queries is a key requirement. Hence, the goal is to store all information as a linked data database organized based on an ontology particularly designed for our purposes. Linked data approaches have recently become very popular to represent archeological information (e.g., Tudhope et al. 2011).

Ontology: The ontology for organizing and querying the linked data storage needs to cover general archeological and historic concepts, concepts related to Mayan history, and more application-specific concepts and relationships related to observation data, models, and media resources. Ontological modeling for archeology and cultural heritage is an active field and has led to approaches such as the CIDOC Conceptual Reference Model (CRM) ISO standard (Doerr et al. 2003) which could form a basis for our ontological modeling work. Challenges here include adequately dealing with metaphysical problems related to existence and temporal change, and with temporal and spatial information available at different scales.

Query interface supporting qualitative and quantitative relations: SPARQL is the de-facto standard for querying linked data. Queries can use quantitative (typically proximity based) relations as well as qualitative relations (spatial "on" and temporal "after", "from"). Spatial and temporal extensions of SPARQL (such as stSPARQL and GeoSPARQL) supporting qualitative relations have been proposed but expressivity and dealing with uncertainty are still major challenges (Belussi and Migliorini 2014).

Automatic VR experience generation: As indicated above, one of our goals is a high-level approach in which content and functionality is specified declaratively and the application is then created automatically from that specification drawing content from the central information system. Such a specification could, for instance, be based on a combination of state machine-like view graphs, rules for view transitions and interactions, and associated queries to the information system.

Flexible VR interface to linked data: To provide archaeologists with the means to conduct analyses and explore the available information in an immersive VR application, things need to be kept very flexible. The idea therefore is to provide researchers with configuration tools and a querying/exploration interface that allows them to choose what is shown and how, and directly interact with the linked data. While visualization and browsing tools for semantic networks exist in 2D, being inside a VR environment opens up new possibilities to interact with linked data.

6 Conclusions and Outlook

We presented work and ideas on creating immersive experiences and immersive digital workbenches for researchers for archeological sites using the example of the ancient Mayan site Cahal Pech. We discussed data capturing and 3D modeling methods as well as first xR applications and interaction methods we designed. These should be seen as first steps that will be improved and extended as part of future work. Finally, we described our plans for basing these applications on an underlying information system based on linked data representation and query technology. While challenges remain regarding the application of these semantic web methods to the archeological domain, we believe the ontology-driven linked data approach is the most suitable one to realize the envisioned xR applications.

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