Immersive Applications for Informal and Interactive Learning for Earth Sciences

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ABSTRACT

Immersive technologies provide novel ways to integrate data with their context. This integration has brought tremendous opportunities to blur the distinction between classroom-based formal learning and informal learning in the outside world. Additionally, the ability for virtual navigation to real world sites has converged space and time. To further the understanding of such opportunities, this paper presents an ongoing project that integrates heterogeneous datasets (i.e., tabular data, 360° photos, and videos) with the 3D photorealistic model of a real-word object in a comprehensive suite of immersive applications (i.e., virtual and augmented reality, collectively known as xR). Our xR prototype provides an immersive analytical environment that supports interactive data visualization and virtual navigation in a natural environment. This work-in-progress project can provide an interactive immersive learning platform (specifically, for K-12 and introductory level geosciences students) where learning process is enhanced through seamless navigation between 3D data space and physical space.

Keywords: Virtual reality, augmented reality, immersive learning, immersive analytics, geosciences, Obelisk

Index Terms: Human-centered computing~Mixed/augmented reality; Human-centered computing~Virtual reality; Applied computing~Interactive learning environments; Social and professional topics~K-12 education

1 INTRODUCTION

Recent years have seen immersive technologies on the rise, which brought new forms of information and scientific visualization [1]. Immersive technologies created a new platform of data analytics - known as *Immersive Analytics*, which essentially is a form of Visual Analytics [2], [3]. Immersive Analytics leverages new display technologies and provides new forms of interaction to support analytical reasoning and decision making [4]. Currently, the spectrum of available immersive technologies that support interactive, visual analytic tasks is quite rich. Henceforth, we refer to them collectively as xR - which primarily includes Virtual Reality (VR) and Augmented Reality (AR).

As discussed in [5], in a VR environment the participant observer is totally immersed in, and able to interact with, a completely synthetic world. Whereas, in an AR environment, the real environment is augmented by means of virtual (computer graphic) objects. In a software environment, xR technology can bridge between real and *virtual* (VR) and *augmented* (AR) worlds [5]. Hence, VR and AR software applications have the capacity to emulate real-world experiences through seamless navigation between a 3D data space and physical space, which can enhance cognitive and analytical processes in, for example, Earth Sciences education.

This paper presents an interactive xR system for integrated, seamless information visualizations and immersive experiences that can assist human cognition in assimilating information and learning about real world features (i.e., geological and archeological). Although research on immersive teaching and learning goes back decades [18], [19], our goal is to investigate strengths of most current and sophisticated xR technologies in supporting immersive, visual analytical tasks. In doing so, we have put importance on the effective xR interface design and immersive interactions to ensure the desired playability and engagement. The design and interaction framework of our xR system (Figure 1) allows users to visually interact with and virtually navigate between dynamically linked 3D real-world objects, data (both spatial and non-spatial), and multimedia contents (e.g., 360° images).

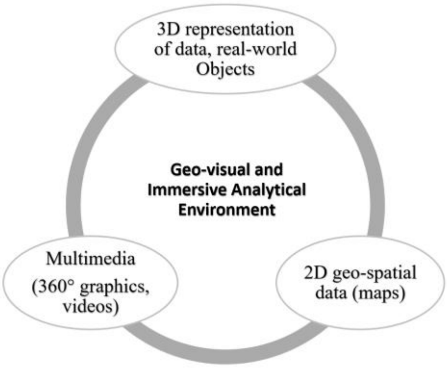

Figure 1: Our xR System Framework: dynamically linked views to support geo-visual and immersive analytical tasks

On the one hand, multimedia contents and 3D models provide a view from within the object or space (i.e., egocentric frame of reference) which enables users' actional immersion and motivation through embodied, concrete learning. On the other hand, maps and other 2D geospatial data provide a view of an object or space from the outside (i.e., exocentric frame of reference) which fosters more abstract and symbolic insights gained from distancing oneself from the context. Attribute data and real-world objects seamlessly bridge these two types of perspective and information behind them. Users are able to flexibly shift

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between egocentric and exocentric frames of reference to combine benefits gained from the bicentric experience. Thus, our framework essentially provides an integrated geo-visual and immersive analytical environment that can be adapted and utilized to enhance the learning process, analytical reasoning and decision-making tasks in various real-world contexts, for example, in providing virtual field trip experiences to geosciences students, making better sense of people, places and world events through immersive exploration of geo-located tweets, etc.

Here, we focus on an immersive experience of an artistic expression of the geological history of Pennsylvania, the Penn State Obelisk [6], to become an efficient immersive learning and analytical tool. To create immersive, interactive experiences, the following components were realized: immersive exploration of 3D objects, interactive information visualizations in the immersive environment which connects a database to the object's components (geologically ordered rocks), and immersion into the natural environment corresponding to those components in the form of 360° images taken at the quarries from which the rocks were mined. The Penn State Obelisk is one of the oldest landmarks at the Pennsylvania State University. It was constructed of building facies stones used throughout the Commonwealth of Pennsylvania and beyond. Our project integrates an external database of the Obelisk's rock faces, a manually created photorealistic model of the real-world Obelisk, and 360° photography and videography of the rock quarries where the rocks were mined in and around the commonwealth of Pennsylvania. With these data, this project aims to create an interactive information visualization and immersive exploration for different xR technologies: Head mounted displays (e.g., HTC Vive, mobile VR solutions), and augmented reality (AR). The overarching goals of the project are: 1) the use of artistic expressions as learning tools, and 2) the potential to turn any environment into an interactive learning experience through xR.

Traditionally, learning is achieved in the classroom or through field trips that allow access to real-world example; for example, a field trip to a geologic outcrop. In this learning process, content is often organized and fetched onto a 2-dimensional interface (i.e., book, computer interface) for a user to capture and process. xR technologies, on the other hand, provide a 3-dimensional medium that allows a wider field of view and an improved peripheral vision for the displayed content as well as immersive experiences [7]. Therefore, xR poses tremendous potential for an educational and research platform that can enhance learning and memorizing processes by offering an improved, interactive 3D visualization and immersive environment.

Section 2 describes the background of our Obelisk-xR project. Section 3 provides details on database and 3D model development. Section 4 describes Obelisk-xVR system design, workflow and immersive experiences. Section 5 concludes with project outcomes and future work.

2 BACKGROUND

2.1 The Penn State Obelisk

The Obelisk (Figure 2) is a well-known landmark on the University Park campus at The Pennsylvania State University and is composed of 281 stones from 139 different localities in and around Pennsylvania (i.e., Ohio, New York, New Jersey, Connecticut, etc.). The blocks of stones are assembled in their natural geologic order with oldest rocks (Precambrian Era) at the bottom and the youngest (Triassic Period) at the top. This "polylith" landmark was constructed in 1896 and stands 32.7 feet high with a weight of 53.4 tons.

Standing tall as one of the oldest monuments on the UP campus, the Obelisk represents geologic history and thus stands as an emblem and sense of the past environments of Pennsylvania and the region. This sense of past environments may be evoked easily to knowledgeable eyes and guided tourists. Whereas to a layman passing by, this monument with geologically and environmentally rich contents may only provide a sense of beauty and craftsmanship. Therefore, an effective information visualization system can bridge the gap between an emblematic object and the information it carries.


(a) (b) (c)

Figure 2: (a) Obelisk in the 1890s. (b) Present-day Obelisk. (c) A close-up view of the Obelisk's stones.

2.2 xR as a Learning Environment

Generally, formal learning is achieved in classroom-based environments, whereas informal education usually happens outside of the classroom (e.g., libraries, home, museum, playground). xR technologies are blurring this distinction by enabling an experience-based learning through immersion [8]. Slater [9] defined immersion as the extent to which the actual system delivers a surrounding environment. According to Slater, immersion is a description of technical affordances of the system (e.g., the size of the screen displays or the field of view of the HMD). In immersive VR (iVR), the systems can continuously track user's' position and viewing angle to display real-timely corresponding contents to the display with high resolution. Besides, the HMD wraps around eyes which gives users ability to perceive the mediated spatial environment compatible with their embodied imagination. With the immersion, users feel the simulated world is perceptually convincing, that he or she actually is "there" [10]. Considering this, immersion in geospatial context can be very useful as it fosters imagination and provides way to travel across space and time.

Empirical studies have shown the potential of xR in the teaching-learning process [11], [12]. One of the biggest advantage of xR for learning is that it affords learners a direct feeling of objects and events that are physically out of reach. In this way, learners can live and experience the situations that are impossible or difficult to be accessed. Besides, the introduction of stereoscopic depth into iVR projection systems presents stimuli in three dimensions which can not only bring learners to complex themes of hard learning and often takes care of the difficulties associated with abstract data visualization, but also takes the learning and teaching process into a more controllable stage [13]. Further, game engines (e.g., Unity3D) adopted for xR application development increases the learner's involvement and motivation which widens the range of learning styles supported.

3 OBELISK DATABASE AND 3D MODEL DEVELOPMENT

This work-in-progress Obelisk-xR project makes use of the following datasets:

3.1 Obelisk Stone Database

The Penn State obelisk's stone information is available online [14]. Each stone has the following attributes: name, type of rock, description, map (showing estimated position of the Earth's continents when this rock was being formed), geologic era of formation, thickness, and sources of the stone (map, name of the individual quarry, nearest town, and county/state). All the information for each stone have been organized and stored in our database.

3.2 Structure from Motion 3D Modeling

Structure-from-Motion (SfM) mapping is a technique that allows for the construction of photorealistic point clouds using photographic images and photogrammetric techniques. Agisoft PhotoScan Pro (http://www.agisoft.com/) is a rapid 3D modeling software that intuitively stitches together photos to from 3D geometry. The principle of PhotoScan and SfM is parallax imaging similar to how humans use their eyes to observe objects in their surroundings. With two images of an object available taken from different perspectives, those two images can generate a stereo view (i.e., the initial form of a 3D model) according to the depth created by the parallax between these two images through identifying where the zero parallax is [15].

114 photos of the Obelisk were taken and imported into PhotoScan as the first step to construct a photorealistic 3D model (Figure 3).

Figure 3: Photos were taken around the Obelisk along a circle to cover its surface with a reasonable overlap rate (~50%) between each pair of neighboring photos. Blue rectangles indicate the positions and attitudes of the camera positions estimated by Agisoft PhotoScan Pro.

Because the Obelisk is box-shaped, this regular shape allows for adopting a standardized shooting approach normally used in collecting photos for SfM mapping. When taking pictures, specifically, the modelers stood still and vertically rotated the camera lens pointing towards the obelisk from bottom to top to execute interval shooting. After that, the modelers would move for a slight distance to the side and repeat the vertical interval shooting. The modelers kept moving till making a loop around the target keeping the horizontal distance consistent during the lateral movement.

3.3 360° Photography and Videography

As discussed above, each stone has a location associated with it where it was excavated in 1896. While some of the locations have changed their appearance, many of them are still accessible. For example, Markle quarry, Huntington Co., Indiana and Clarion quarries in Pennsylvania. We started to revisit the locations where the stones are excavated and took 360° images with a high-resolution camera. These images are accessible within the xR experience (see below). Part of our work-in-progress is collecting 360° video recordings of location/stone combinations that will be associated with images/locations.

4 OBELISK-XR SYSTEM DESIGN, WORKFLOW, AND XR EXPERIENCES

A prototype of the Obelisk xR system has been developed in Unity3D primarily for the HTC Vive. The HTC Vive allows for room-scale xR experiences needed to evaluate the interaction workflow for desired immersive experiences at successive stages of prototype development. However, we are working on extending our prototype to mobile phones and tablets, and the realm of augmented reality.

4.1 Conceptual Design and Workflow

A set of benchmark tasks guided the development of the conceptual model of Obelisk-xR. The initial conceptual model has evolved at subsequent prototype revisions. Our work-in-progress project has adopted a multi-dimensional, in-depth, and long-term case study (MILC)-based approach [16], which focuses both on the usability and utility aspects of the prototype. Upon completion of the project, a summative evaluation will be carried out to examine how well visual interfaces perform to achieve user's (e.g., K-12 and introductory level geosciences students) expected goals.

At the current stage of development, the Obelisk-xR application tool supports interactive visualization and immersion. For the immersive analytics, our system supports tasks ranging from initial exploration of the Obelisk 3D model to the immersive analytics of the natural environment. Since the entire workflow is done in a xR environment, we characterize the entire immersive experience as a Virtual Field Trip (VFT). The following VFT workflow is supported by the Obelisk-xR system for facilitating immersive exploration and analytical tasks:

i. Visual Exploration: Initial visual exploration of the Obelisk 3D model
ii. Information Visualization: Visualization and inspection of object's properties (taken from the database)
iii. Immersion in xR: Immersion into object's natural environment (present and past)

4.2 Obelisk-xR Experience

4.2.1 Virtual Exploration of the Obelisk

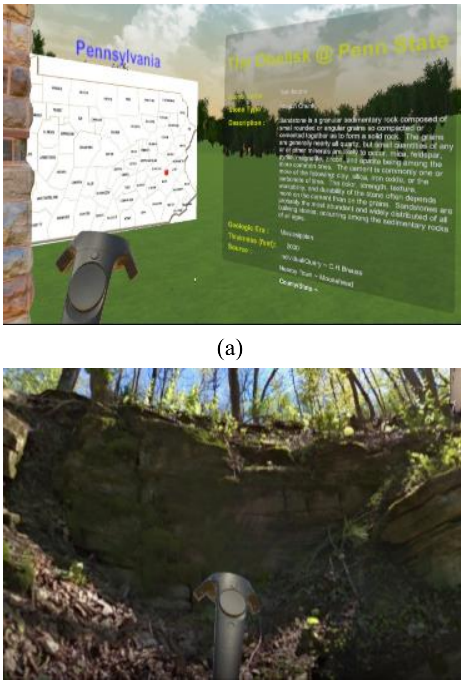
Using the HTC Vive, the user can physically walk around the Obelisk 3D model in the simulated space (Figure 4a). By maintaining a 1:1 body scale in the simulated space, the user can visually explore physical objects. In this case, by walking around the 3D photorealistic model of the Obelisk, the user can visually investigate stone characteristics (i.e., size, shape, color, texture, etc.). Based on this initial visual exploration an intuitive understanding of the stone object's geology can be achieved, which is further assisted in the next step of user interactions.

4.2.2 Information Visualization

Using the HTC Vive controller, once the user points to any stone object on the 3D Obelisk, attribute information for that object is called from the database and displayed along the user's line of sight, exploiting the wider field of view in the iVR environment (Figure 4a). Both spatial (i.e., stone's quarry as a point on a map) and non-spatial (i.e., name, type, description, geologic era, thickness on Unity Canvas screen) attribute information are queried and presented at this stage.

4.2.3 Immersion into the Natural Environment

Once the stone location point is visualized on the map, the user can activate a laser emitted by the tip of the hand controller and point it to map points providing access to the 360°-degree photos or videos. In this work-in-progress implementation, a 360° photo represents a present-day environment of the stone's parent location (Figure 4b).



(a)

(b)

Figure 4: (a) A stone's spatial and non-spatial information visualization. (b) Immersion into the natural environment.

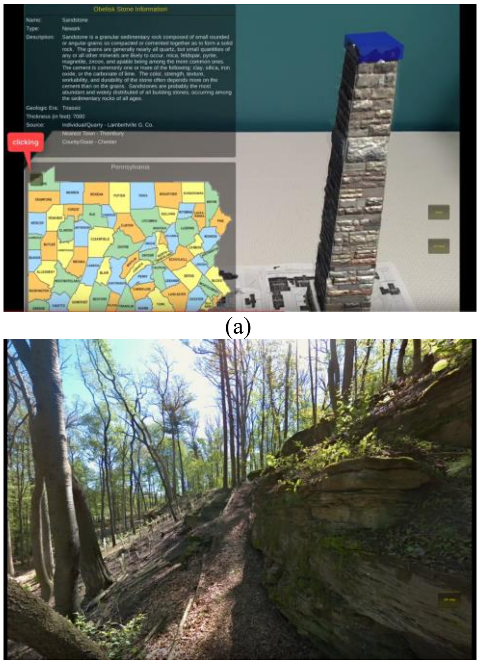
According to the uniformitarian principle, "The present is the key to the past." It means that understanding the present day natural processes of geologic formations can inform about similar natural processes that operated to construct past environments. Through this understanding comes the formulation of the causal relationships among natural system components across space and time. By facilitating visual exploration and analysis of present-day natural environments, the Obelisk-xR application provides a unique way to connect present to the past.

5 OBELISK-XR OUTCOME AND FUTURE WORK

We presented and discussed data, design, workflow, and immersive experiences of the VR version of our Obelisk-xR project. Currently, development of the Obelisk-AR version is underway (briefly discussed below) to support Situated Analytics [17]. Future work will include gathering more 360° images and videos of the Obelisk's stones across the entire commonwealth of Pennsylvania and beyond. We also intend to create and visualize 3D models of geologic times for each stone. Finally, upon completion we aim to perform summative assessments (that include usability and utility tests) of our Obelisk-xR applications and make them publicly accessible for educational and learning purposes. We strongly believe, this project will benefit geosciences education in the classrooms and beyond.

Obelisk-AR version:

With recent development of novel, interesting AR and mixed reality-based applications for public outdoor activities, such as Riverwalking in Chicago [20], scavenger hunts [21], [22], and game-based learning [23], strenths and limits of these advance immersive medias for educational purposes demand scientific evaluation, as suggested in [8]. Hence, in this ongoing project we are incorporating AR components to examine learning outcomes in an educational setup. Our Obelisk-xR system combines both location- and marker-based AR experiences. Location-based AR refers to the use of internal GPS signal of mobile devices to position virtual contents on the screen (Figure 5).



Name: Sandstone
Type: Newark
Description: Sandstone is a granular sedimentary rock composed of small rounded or angular grains so compacted or cemented together as to form a solid rock. The grains are generally nearly all quartz, but small quantities of any or all other minerals are likely to occur, mica, feldspar, pyrite, magnetite, zircon, and apatite being among the more common ones. The cement is commonly one or more of the following: clay, silica, iron oxide, or the carbonate of lime. The color, strength, texture, workability, and durability of the stone often depends more on the cement than on the grains. Sandstones are probably the most abundant and widely distributed of all building stones, occurring among the sedimentary rocks of all ages.
Geologic Era: Triassic
Thickness (in feet): 7000
Source: Individual/Quarry - Lambertville G. Co.
Nearest Town - Thornbury
County/State - Chester

(a)

(b)

Figure 5: Location-basesd AR interactions of Obelisk-xR system. (a) Touch input on Obelisk 3D model visualizes stone and spatial information on the GUI windows. Touch input on the map points switches AR view to the environment view (360° image) (b).

On the other hand, the marker-based AR uses image textures or physical objects as the target in which feature points are recognized and treated as reference points to anchor virtual contents with high accuracy. Our marker-based Obelisk-AR is currently under development. We plan to apply location-based Obelisk-

AR for distant users while marker-based Obelisk-AR for users adjacent to the Obelisk in the physical environment. This bicentric experience combines virtual contents with the real physical environment in a large scale of spatial context as a promising way to conduct situated learning.

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