Comparison of Interactive Environments for the Archaeological Exploration of 3D Landscape Data

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Abstract

The increasingly widespread availability of high-accuracy terrain models is revolutionizing our understanding of historic landscapes across the globe, yet much of this inherently 3D data is viewed and analyzed using 2D Geographical Information System (GIS). The ability to explore the environments in a more immersive way that takes advantage of the full data content is advantageous for professionals and researchers, but is also highly desirable for education and public outreach. This paper describes the method and outcomes of a comparison of three virtual environments; a six-sided CAVE-type immersive virtual reality system (referred to henceforth as CAVE); a 3D web application and a standard 2D desktop paradigm in the form of a GIS. Two groups of participants were used to reflect specialist and non-specialist interests.

This study showed that while the 2D GIS, the most common interface for exploring archaeological data, is well-suited to expert interpretation (based on previous familiarity with the system), it is significantly harder for non-specialists to undertake a feature identification and location task in this environment when compared with the 3D environments. Specialist users also mostly preferred the ability to view terrain data in 3D. The experience of fully-immersive CAVE-type system was valuable for a sense of place and contextualizing features in a way that was not possible in the other environments. However it was not shown that this led to improved archaeological observations during the exploration and there is some evidence that the lack of orientation made recounting features in the reflection time more difficult. Although small-scale the experiment gave valuable insight into the use of the different environments by specialist and non-specialist groups, allowing the 3D web application to be identified as the optimal environment for pedagogical purposes.

Keywords: virtual reality, immersive environments, pedagogy, archaeology, landscape visualization

Index Terms: H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems-Artificial—augmented, and virtual realities; H.5.2 [Information Interfaces and Presentation]: User Interfaces—Evaluation/methodology; I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism—Virtual reality

1 Introduction

The use of 3D digital terrain models derived from airborne laser scanning, combined with traditional aerial photographic analysis is becoming standard procedure in academic, commercial and curatorial contexts for investigating archaeological landscapes across the globe [1, 2].

The interpretation for this task, however, requires a high level of skill as users must combine their understanding of the archaeological landscape with understanding the properties of the data and sensor platform. Therefore, there is a strong imperative to rapidly build this skill set, teaching students and professionals how to interpret these data and access the information they contain.

Traditional approaches to this rely entirely on the use of Geographical Information Systems (GIS) in desktop-based analysis, a 2D schematic representation within a complex interface that in many respects fails to adequately convey the attributes of the 3D and high dimensional data. Previous studies into the 3D representation of data give contrasting results with some illustrating improved spatial memory [15]. However, the Southampton York Archaeological Simulation System project, a pedagogical experiment to teach excavation skills in a virtual environment, illustrated some of the pitfalls of attempting to convey complex concepts against the distraction of virtual reality [14].

Such an approach has not been trialled for introducing the principles of landscape archaeology and given the increasing familiarity with 3D environments, and the nature of the data to be assessed we propose that use of 3D interfaces will better represent the dimensionality of the terrain data and consequently improve understanding of the landscape. In order to test this hypothesis and to aid our understanding of human-computer interaction in this particular scenario, three different interactive environments were compared in controlled conditions.

2 Background

In modern archaeological research, it is hard to underestimate the importance of GIS. It facilitates handling complex, multi-scale datasets covering entire landscapes and individual sites, and provides the basis for site, regional and national records of the historic environment. For this reason alone using GIS should be a key part of any pedagogical approach to the discipline. Archaeologists have also been at the forefront of attempting to use GIS to visualize or recreate human perception of landscape using spatial data [6]. Yet the standard GIS only visualizes data well in two dimensions, leading us to question how well it can provide a realistic representation of landscape.

For those well versed in the use of GIS environments, their specific skill-set is widely considered to allow transcendence of limitations of the platform. However, there is a distinct pedagogical challenge when introducing new students to landscape archaeology. They must seamlessly combine an understanding of the data, viewpoint and character of the terrain, geology and vegetation while also deploying interpretation skills to identify the aspects of the scene that relate to past human occupation and use of the landscape. For this type of study, there is no substitute for combined desk-based research and field observations, but there is a relatively unexplored technique between the two, where students can try out their nascent interpretation skills in a digital recreation of the landscape.

Virtual reality is not a novel concept in archaeological research but mostly to date it has been seen as the conclusion of a process, for example the reconstruction of buildings or cityscapes for educational or entertainment purposes [6, 7, 8, 11, 14, 16]. Almost invariably, the audience for such models is the general public and there is no doubt that in terms of communicating a theory regarding past appearance, digital reconstruction is a powerful tool.

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(a) GIS Desktop

(b) 3D Web Application

(c) CAVE-type immersive system

Figure 1: Interaction Paradigms Tested

Examples of digital environments being used as a pedagogical tool in archaeology are few, however, despite the proven success of virtual environments for education [3]. Given the increasing availability of landscape scale imagery and terrain models derived from airborne or satellite platforms, the need to train the next generation of archaeological researchers and professionals to interrogate these data is pressing. The experiment detailed here was established as a first step towards assessing the impact of 3D visualization on the participants' approach to landscape assessment with the aim of clarifying the benefits or disadvantages of different visualization environments for teaching.

3 Development

Three representative landscapes were selected to be converted into 3D models for this study, containing a roughly equal number and range of positive, negative and modern features in all quadrants of the landscape. Environmentally, they were identical, comprising gently undulating, chalk grassland mostly under pasture with occasional stands of scrub and trees. This equality of environmental and archaeological parity was important to ensure comparability between landscapes.

The data used in the study were converted from GIS data stored in GRASS [9] to formats suitable for the creation of 3D environments. The final dataset comprised a terrain model and various overlays (Figure 2) which were imported into Virtools [4] and developed as the CAVE and 3D web interactive models (Figure 1). The models incorporated navigation along with the ability to change overlay and to add a layer representing a selection of help features of archaeological origin. The GIS interface was a paired-down version of QGIS 1.8 [12] retaining only the ability to pan and zoom and switch layers on and off for comparability to the other environments.

3.1 CAVE System Technical Details

We used the Duke immersive Virtual Environment (DiVE), a six-sided active stereo CAVE-type system. Head tracking with 6 degress of freedom (DOF) was provided by an Intersense IS-900 tracker. The input device was an Intersense IS-900 wand controller, which provides 6 DOF pointing ability, buttons, and a 2 axis joystick. Participants wore Crystal Eyes CE3 shutter glasses synced to projectors running at 110hz. As active-stereo alternates between left and right displayed frames, this led to an effective frame rate of 55hz for the user. A cluster of computers (1 computer per projector) plus one computer as a master computer powered the system.

3.2 Method

The comparison of interfaces was undertaken using the three environments described above. Three visually similar but archaeologically distinct landscape models were used to counter balance for learning effects, but landscapes were always viewed in the same order. As an additional counter balance, the order in which the interfaces were experienced was also counter balanced.

Two groups of six participants were enrolled in the study; one with experience of archaeological landscape analysis (Group A) and one without any prior knowledge of the discipline (Group B). After introduction and explanation of the protocol, each participant was given the task of identifying archaeological features in the environment. A "think-aloud" protocol was used to record the participants' narration of their navigation through the landscapes, their observations of the environments and identification of archaeological features. The audio for each participant was transcribed and coded.

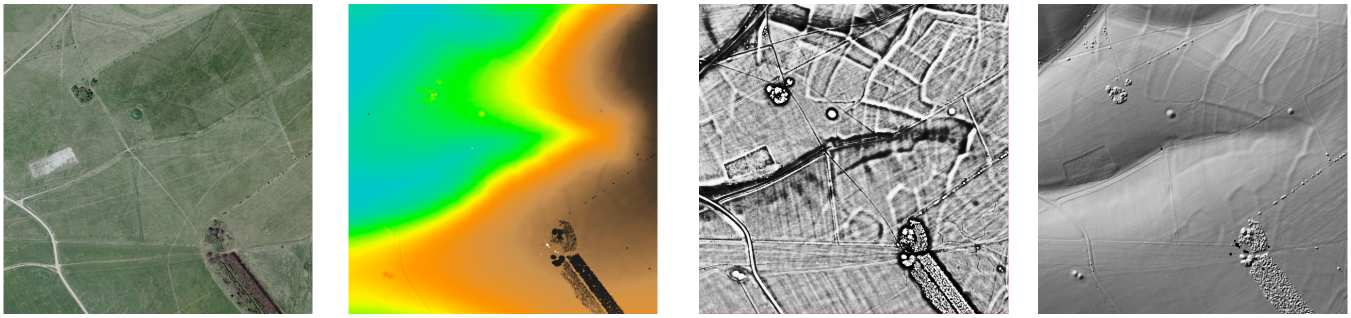
In addition each participant was asked to take two minutes reflection time after using each environment to write down their observations in writing. A printed aerial photograph of the landscape was supplied so that they could make annotations. The observations thus recorded were scored by completeness and level of interpretation along with a note of whether the participant preferred spatial (annotated sketch) or textual descriptions. On completion of the experiment a summary survey was conducted to collect details of the participants prior experience and preferences / comments regarding the environments. The quantitative results of this survey for each environment were scored in two categories: usability of the interface and suitability to the archaeological task given.

4 Results

Although a relatively small study, by recording both the real-time use and reactions in addition to reflective tasks and a summary survey, it was possible to assess a number of different aspects of each participant's interactions with the environments.

4.1 CAVE-type Immersive System

The fully immersive experience was preferred by the majority (62%) of the participants for exploring the data. Many thought of this as a more natural experience of the landscape, with more intuitive interactions that did not get in the way of the identification task that was set. Many commented on the enhanced sense of place in the landscape that was given in this environment, and the ability easily transition from a 1st person view at one position to a bird's eye view of the broader context. Some also found distinguishing



(a) Aerial Photograph (b) Elevation Map (c) Local Relief Model [10] (d) Hillshade [5]

Figure 2: Different visualization layers available to the user

between natural and archaeological features easier in this environment. Participants found the ability to point and zoom to areas of interest while maintaining the visual cue of the wand pointer helpful when determining the shapes of features. Only one participant ranked the CAVE last as commenting that the low resolution was a disadvantage. As the resolution of the data in all three environments was identical this is assumed to be a consequence of the participant using a higher zoom level.

The quantitative results from the summary survey show that the CAVE was considered by the participants to be the most suitable to the archaeological feature identification task set. The participants also ranked the CAVE highest on the usability of the interface, with little difference in scores between the study groups.

The assessment of the success of the task set via counts of archaeological observations in the audio transcript and the graphic/textual materials produced during the refection period draw a slightly more nuanced view of the usefulness of the CAVE environment for archaeological landscape exploration. The CAVE had a lower median score for archaeological observations during the experiments and interpretations in the reflection period than any other environment. This appears to be particularly true of the specialist group with the general group exhibiting more parity of response across the environments.

Users also scored lower on completeness when reflecting on the landscape explored in the CAVE, indicating that they did not observe, or did not remember features within all four quadrants of the landscape. It was shown that overall the archaeological observations from the CAVE (as recorded in the reflection time after the use of each environment) were poorer in the specialist group than for the non-specialists. This is also reflected in the audio transcript, where a lower number of features were identified and interpretations made in the CAVE compared with other environments. Finally, it was also noted that the participants in both groups narrated slightly fewer interactions (movement, pan and zoom) with this environment compared with the 3D web application and GIS environments.

4.2 3D Web Application

In the summary survey, 23% of participants named the 3D web application as their preferred environment, with users commenting that it provided a more intuitive navigation than the GIS interface less disorientating experience than the CAVE with the better resolution and brightness. An equal number named this interface as their least favorite, citing difficulties of orienting features (especially in the reflection exercise), a less immersive 1st person experience when compared with the CAVE and slower view transitioning. These final two points are linked as the zoom speeds were identical between the CAVE and the 3D web application, leading to the conclusion that the perception of difference in speed is due to the reduced field of view and immersion of the 3D web environment.

For the combined results of the reflection graphic and text exercise the 3D web environment slightly outperformed the CAVE on median score. In the specialist group the environment scored better for completeness and interpretation on average than the CAVE, but underperformed compared with the GIS. Additionally the audio transcript demonstrated more observations about archaeological features in this environment when compared with the CAVE, especially for the non-specialist group. Scores for completeness were mixed, with the specialist group scoring lower than the non-specialists.

4.3 GIS 2D Desktop Application

The GIS interface was the least popular of the environments tested (69%). Only one participant selected this as their preferred environment, citing that previous experience led them to feel more comfortable with this environment than the others. Participants commented that the lack of easy access to variety of view angles inhibited their ability to discern the topography of features in comparison with the other environments, and that the controls were not as intuitive. The qualitative survey places the GIS last by a significant margin in suitability and ease of use.

The GIS interface scored most highly with the specialist users in the completeness and interpretation criteria of the reflection task. All the specialist users had previous experience of a GIS system and their familiarity with the environment may have contributed to the high interpretation score. The completeness scores were higher in this environment than any other across all groups as were the number of navigations undertaken by the participants.

5 Discussion

The picture that has emerged from this small study is very informative for understanding how users interact with and gain information from topographic data across the three different environments. While the participants clearly expressed a preference for the immersive experience of the CAVE for examining the landscape, the mixed-method analysis shows that that use of the CAVE did not lead to substantially improved archaeological observations either during the exploration or in reflection time. Additionally the completeness of recorded observations was lower for both 3D environments indicating that users had not explored (or did not recall) the whole landscape. Plotting features back to 2D to enable concurrence with maps for use in the field is a key skill for archaeological interpretation and some participants also struggled to orient their 3D experience back to a 2D image in reflection time. This, along with the incumbent memory test of the exercise and potential reticence about committing 'incorrect' ideas to paper, could account for the generally lower quality of archaeological interpretations across all groups in the reflection period than while using the CAVE environment. It has been suggested that the landscape modelled for this study was relatively flat in terms of the macro-topography and had there been greater contrast in topography, the CAVE system may have proved more effective in allowing users to orientate themselves.

Overall participants made fewer archaeological observations when using the CAVE compared to the other environments. As the landscapes and order of experimentation were carefully designed to mitigate feature number discrepancies and learning effects, the likely cause of this is the novel nature of experiencing landscape data in this way. Although almost half the participants had used an immersive 3D environment before, the majority of immersive environments are relatively limited in extent. The audio transcript details participants from all groups being drawn to zoom to prominent features from a wider view and while the eye-level perspective is useful for examining individual features, the 1:1 scale of the topography can obscure relationships between features. While many participants enthused about the enhanced sense of place and context in the CAVE compared with the other systems, it appears that this might inhibit feature identification, at least in the short time-frame allowed for exploration in this study.

In contrast, although more difficult to master, user in all groups exhibited more consistent spatial completeness in their reflections after using the GIS environment. This is most likely attributed to the relative ease with which one can obtain a vertical aerial view of the whole landscape in the GIS environment. The 3D web application divided the participants with many preferring it as naming it least preferable, but the oral and written archaeological observations showed slight improvement over the immersive system.

The fact that the main differences observed between the study groups was in the ability to effectively use the GIS could be seen to indicate that prior experience of archaeological landscape analysis does not confer to an automatic advantage in using the 3D environments. This strongly indicates that the design of interaction with the display environment, the human-computer interface and navigation is as critical for expert users as for non-specialists. With this in mind there could be value in expanding future comparison to other interfaces such as stereoscopy (which is used extensively for aerial photograph analysis in archaeology but not for analyzing terrain models) or affordable immersive systems

6 Conclusion and Future Work

This study illustrated that while the GIS, the most common interface for exploring archaeological data, is well-suited to expert interpretation (based on previous familiarity with the system). However it is significantly harder for non-specialists to undertake a feature identification and location task in the GIS environment when compared with the 3D environments of the CAVE and 3D web application. Specialist users also mostly preferred the ability to view terrain data in 3D.

The experience of fully-immersive CAVE system was valuable for a sense of place and contextualizing features in a way that was not possible in the desktop environments. However it was not shown that this led to improved archaeological observations during the exploration and there is some evidence that the lack of orientation made recounting features in the reflection time more difficult. This result reflects that of previous studies though was not as dramatic as observed elsewhere [14] and there is not considered as great an impediment to learning in the virtual environment. It has also been shown that providing the user with free navigation (rather than a guided path), may actually decrease learning [13]. Perhaps this is because of cognitive load going towards manipulating controls, rather than absorbing knowledge. Based on this, a number of improvements to the basic immersive experience could be suggested for pedagogical purposes, including a guiding narrative (audio or instructor) and the ability switch to overview map detailing current position and cardinal direction.

Practically, the most distributable 3D environment is the 3D web application as it can be run on any computer with a compatible browser. Taking this into consideration alongside the overall performance of this environment, suggests that there would be value in further development of such a pedagogical tool to enhance teaching of archaeological landscape analysis.

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References

[1] R. Bennett. *Archaeological Remote Sensing: Visualisation and analysis of grass-dominated environments using airborne laser scanning and digital spectra data*. PhD thesis, Bournemouth University, 2011.

[2] R. Bennett, K. Welham, R. A. Hill, and A. Ford. Making the most of airborne remote sensing techniques for archaeological survey and interpretation. *Remote sensing for archaeological heritage management. EAC Occasional Paper*, (5):99–106, 2011.

[3] D. A. Bowman, L. F. Hodges, D. Allison, and J. Wineman. The educational value of an information-rich virtual environment. *Presence: Teleoperators and Virtual Environments*, 8(3):317–331, 1999.

[4] Dassault Systemes. Virtools 5.0. `http://www.3ds.com/products-services/3dvia/3dvia-virtools/`, 2009.

[5] B. Devereux, G. Amable, and P. Crow. Visualisation of lidar terrain models for archaeological feature detection. *Antiquity*, 82(316):470–479, 2008.

[6] S. Eve. *Dead men's eyes: embodied GIS, mixed reality and landscape archaeology*. PhD thesis, UCL (University College London), 2014.

[7] M. Forte. Virtual worlds. In N. A. Silberman, editor, *Oxford Companion to Archaeology*. Oxford University Press, Oxford, 2013.

[8] R. Gaugne, J.-B. Barreau, G. Le Cloirec, and V. Gouranton. Experiencing the past in virtual reality: A virtual reality event for the french national days of archaeology. In *Cognitive Infocommunications (CogInfoCom), 2013 IEEE 4th International Conference on*, pages 75–80. IEEE, 2013.

[9] GRASS Development Team. *Geographic Resources Analysis Support System (GRASS GIS) Software*. Open Source Geospatial Foundation, 2012.

[10] R. Hesse. Lidar-derived local relief models–a new tool for archaeological prospection. *Archaeological Prospection*, 17(2):67–72, 2010.

[11] T. Kerr. The search for 18 rabbit: Virtual archaeology and games based learning. In *ASCILITE-Australian Society for Computers in Learning in Tertiary Education Annual Conference*, volume 2010, pages 508–510, 2010.

[12] QGIS Development Team. *QGIS Geographic Information System*. Open Source Geospatial Foundation, 2009.

[13] E. D. Ragan, K. J. Huber, B. Laha, and D. A. Bowman. The effects of navigational control and environmental detail on learning in 3d virtual environments. In *Virtual Reality Short Papers and Posters (VRW), 2012 IEEE*, pages 11–14. IEEE, 2012.

[14] P. Reilly. Three-dimensional modelling and primary archaeological data. In *Archaeology and the information age: a global perspective*, pages 147–176. Routledge, 1992.

[15] M. Tavanti and M. Lind. 2d vs 3d, implications on spatial memory. In *Information Visualization, 2001. INFOVIS 2001. IEEE Symposium on*, pages 139–145. IEEE, 2001.

[16] E. Unver and A. Taylor. Virtual stonehenge reconstruction. In *Progress in Cultural Heritage Preservation*, pages 449–460. Springer, 2012.

Appendix: Summary data table

		User Type	CAVE (mean)	3D Web (mean)	GIS (mean)
Audio (count of observations)	Archaeological Observations	All	6	6	7
		Specialist	5	6	8
		General	7	6	5
	Navigation Observations	All	13	13	18
		Specialist	12	13	19
		General	13	13	16
Reflection Graphic and Text	Combined Score for Completeness and Interpretation (Max 8)	All	5	5	5
		Specialist	5	6	7
		General	6	5	5
	Score for Completeness (Max 4)	All	2	2	3
		Specialist	2	3	3
		General	3	2	2
	Score for Interpretation (Max 4)	All	2	3	3
		Specialist	2	3	4
		General	3	3	2
Questionnaire	Combined score for Suitability to Archaeological Task (Max 24)	All	14	9	3
		Specialist	7	5	3
		General	7	4	0
	Combined score for ease of use of Interface (Max 24)	All	19	18	16
		Specialist	10	10	9
		General	9	8	7