Position Paper: Immersive Analytics and Deep Maps – the Next Big Thing for Cultural Heritage & Archaeology

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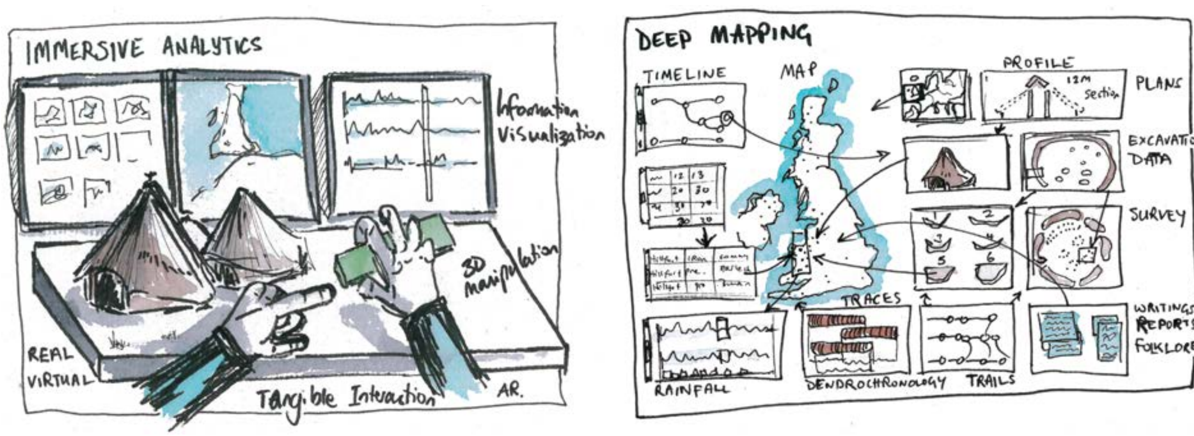

Fig. 1. We present two visions. Immersive analytics where the user can use new-technologies to directly explore and the information. Deep maps, a way for experiencing a narrative through multi-faceted place-specific data.

Abstract— Archaeologists and cultural heritage experts explore complex multifaceted data that is often highly interconnected. We argue for new ways to interact with this data. Such data analysis provides a 'grand challenge' for computer science and heritage researchers, it is big Data, multi-dimensional, multi-typed, contains uncertain information, and the questions posed by researchers are often ill-defined (where it is difficult to guarantee an answer). We present two visions (Immersive Analytics, and Deep Mapping) as solutions to allow both expert users and the general public to interact and explore heritage data. We use pre-historic data as a case study, and discuss key technologies that need to develop further, to help accomplish these two visions.

Index Terms—cultural heritage, digital humanities, alternative representations

1 Introduction

Cultural heritage data contains information relating to monuments, landscapes, architectures, sites, areas, artefacts and archaeological finds. The data is often multivariate, spatial (to various degrees of accuracy), multi-type and of large volume, covering many thousands of years of history. Examples of such data include georeferenced information, photographic recordings, three-dimensional models, topographic and contour maps etc. Collected data from an excavation of a prehistoric site (such as a laser scan) can be in the order of a few terabytes, while thousands of photographs can be captured and used to re-create 3D digital surrogate models via photogrammetry, and additional soil samples, carbon data, sketches, as well as copious notes will be recorded and saved. Often an excavation will be the catalyst to capture and store huge quantities of data, and it will be analysed in-depth and discussed for many years thereafter. It is therefore important to store high quality data at the time of recording and make the information as accurate as possible.

Notwithstanding storing and managing the big data, one of the main challenges is that the queries and problems necessary to perform any analysis are often *ill-defined* [19]. Let us consider a hypothetical example: a team of archaeologists are excavating a prehistoric hillfort site. They find evidence of post holes, they measure the distance of them, and record their positions. The data may nicely fit the assumption of a roundhouse. However, if there are many overlapping holes then the original interpretation of a roundhouse becomes less clear. Is it one house, that has been adapted and changed over a period of time? Is it multiple houses, is it a new type of house? Archaeologists use their experience, and tacit knowledge obtained from other excavations to interpret the information they are presented with. They devise narratives to argue their interpretations. Often leaps-of-faith still need to be made by drawing on and trusting their own experience and body-of-knowledge that has been built up over years of working in the area. Much of this information is tacit and is not explicitly stored or easily exchanged between experts and, in particular, towards learners. As a result, justifying these hypotheses is often difficult without a clear sensemaking process. Moreover, it is sensible to investigate surveys from many locations (integrating data from many databases) and interpretations from other experts, such to gain the best (perhaps most certain) view.

To summarise, cultural heritage and archaeological data is huge,

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and research questions are often ill-defined: experts need to draw on disparate data sources (stored in a variety of databases), correlate and compare the data (both physical and abstract) across several locations, build narratives and tell stories based on said data (i.e., they need to be able to record their findings and play them back) such that they can argue their interpretation. Moreover, many experts need to work together, or at least see the stories of other people, in order to strengthen the overarching interpretation and explication of the data. There is therefore huge potential to use a wide variety of analysis and display techniques, from data analysis, deep learning, data-mining, to information visualization and 3D scientific visualization.

We propose that there are two new technologies that can make a step-change in the processing and understanding of heritage information: (i) **Immersive Analytics** [3], where a user is immersed within their data, and they can investigate the information through immersive environments, natural interaction, tangible user interfaces and mixed reality [20,21], and (ii) **Deep maps** [1], where geo-locatable media allow a multivariate, multispectral and multidimensional understanding of a place and are presented to the user in alternative ways. Deep maps allows tacit knowledge to be made explicit, and experts to make stories, draw upon users memories, folklore, allows different types of data to be integrated (such as weather, interviews, history, scientific analysis), intuitions to be recorded, and enables many users to explore the data and argue over it.

In this paper, we work through a case study of prehistoric data and explain the challenges that archaeologists and heritage experts face. We explain the opportunities with immersive techniques (ranging from augmented, mixed to virtual reality) that has been made possible by the advancement of technologies such as Head-mounted displays (HMDs), mobile phones, cameras, and the democratization of augmented reality software through tools and libraries such as the ARToolkit [7]. We also explain more about the concept of deep mapping and how it can integrate uncertain and multidimensional data. The aim of this paper is not only to inspire the reader, but to frame two fundamental research areas that could substantially change the way users perform cultural heritage and archaeology investigation.

2 Motivation

Prehistoric sites, such as the burial mound and standing-stone at Bryn Celli Ddu, Anglesey, UK, are of interest to both expert and amateur archaeologists, as well as members of the public that are interested in the area's history. However, for both archaeologists and historians there are still many unanswered questions regarding information such as the significance and use of these sites. Prominent or exceptional sites such as Stonehenge have been comprehensively studied; however even for these sites there remain many questions and theories that are heavily debated.

There are thousands of prehistoric sites throughout United Kingdom (UK) and Europe, especially along the "European-Atlantic Arc" macro-region which contains many examples of "Atlantic Fringe Architecture (AFA)". Many consider some of these sites to be of high significance. However, they have been studied and recorded far less comprehensively, due to their lower prevalence as compared to sites such as Stonehenge. The Atlantic arc region follows the coastline along the West coast of Europe from Portugal to Scotland. Most of these sites are listed in heritage databases (Historic Environment Records (HERs)) such as that held by Cadw. Within Wales, Cadw manage and list these sites as Scheduled Monuments[1].

Some of these sites have been recorded in an acceptable level of detail; however even though the information is part of the public record, the data is often not easily accessible and certainly not in a form that is consumable by the public. Through a brief survey of Wikipedia entries (which we consider to represent a publicly accessible view of these prehistoric sites, with data contributed by Cadw), of these Welsh AFA sites, only half of them have photographs, let alone any further data.

[1]Scheduled monument: an archaeological or historic site that is considered to be 'nationally important' and as a result is given protection against unauthorised change.

Fig. 2. A touch table-top display and tangible interactions of alternative-representations of the Pattern Stone at Bryn Celli Ddu

The HERs of various Archaeological Trusts do provide access to some information, but also have many problems. For example, they are often poorly maintained with weak database integrity and inconsistent formatting. To compound the issue, Archaeological Trusts are often regionally managed. As a result, their practices and styles often vary, even from neighbouring Trusts. Even within a single Trust, the style and comprehensiveness of recording between archaeologists often varies.

Printed books are used heavily in archaeology to distribute information about niche or specific areas of (archaeological) interest. One example is "Standing with Stones" [23]. Soskin's book presents many images of megalithic monuments throughout the British isles. Descriptive books such as "Standing stones" [14] presents artists' impressions of usage of these sites. Resources, such as these books, are mostly targeted at enthusiasts and often contain more information than the relevant HER. The challenge, however, is that it is difficult for an expert to perform new analysis, as the information has already been abstracted into a knowledgeable interpretation.

A systematic approach is required for capturing data (including photographs) of prehistoric sites, as well as better ways to deliver that content (e.g. immersive interfaces). To aid both researchers and the public, similar calls have been made before. For instance, the 2008 Institution of Engineering and Technology (IET) (theiet.org) and British Computer Society - The Chartered Institute for IT (BCS) (bcs.org.uk) Grand Challenges in Computer Science called for "bringing the past to life for the citizen". The public would be able to "see events of the past replayed interactively [...] to explore the circumstances and motivations of the participants, linking the reconstruction to the evidence and receiving explanations of the differencing socio-political perspectives which are relevant to the events" [8]. In terms of expert analysis, systematic capture is required to allow for proper analysis. Figure 2 shows multiple representations of Pattern Stone at Byrn Celli Ddu being examined. Systematic capture enables more thorough analysis to be carried out and to discover more detail, such as the carved rock art in this case.

Archaeologists draw much of their wisdom and knowledge from excavations, scans, recorded data from which they construct theories and interpretations. Much of their knowledge becomes tacit, and so is difficult to verbalise and externalise the reasoning behind a theory/interpretation of the use or importance of a site or artefact. An expert or other user could be interacting with a system that was displaying viewsheds or using pattern recognition to display rock-art. The system could make use of a human-in-the-loop for training and to verify outputs. By interacting with this system the user is going through a visual reasoning process. The user's interactions can be logged and used for analysis of their reasoning and sensemaking process; this information is then useful for quantifying and communicating the process.

3 Immersive Analytics

Cultural heritage has been using computer graphics and related technologies, such as virtual and mixed reality for some time (e.g.,

Fig. 3. Standing stones and other pre-historic monuments are displayed in a gallery interface. Users can walk in the 3D world to explore these different sites. The museum uses the citizen science collected data from the heritageTogether.org project.

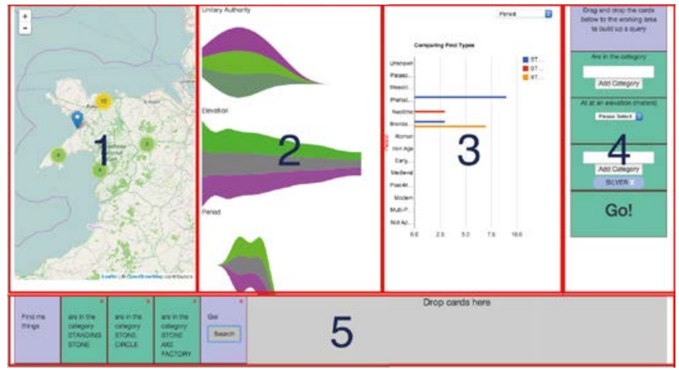

Fig. 4. An interpretation of an HER exploration tool [24] as an example of the sensemaking process. (1) Map Interface, (2) temporal visualizations, (3) categorical data in bar charts (4) query interface to the database, and (5) construction area for visualizations.

[9, 16, 17]), in order to recreate graphical, 2D and 3D, representations of cultural artefacts, monuments etc. Yet, nowadays he have access to cultural heritage data that go beyond mere appearances and physical representations. We have an opportunity to use new forms of immersive experiences, combing multiple quantitative, qualitative and multimedia data about a space/place with the purpose of building a spatial narrative, a story where the viewer can become part of it.

Immersive visualization is a timely topic. In 2014 Donalek et al. [5] wrote about immersive and collaborative data visualization, whereas in 2015, Chandler et al. introduced the term *immersive analytics* [4]. In 2014, Roberts, Ritsos and colleagues [21] discussed the evolution of visualization towards a mixed-reality (MR) world. During 2016 we saw several workshops in Shonnan, IEEE VR and Dagstuhl focused on Immersive Analytics. Even before 2014, researchers have been looking to other modalities and techniques to display data. Paneels and Roberts [15] looked at haptic visualization, Kramer [11] writes on sonification, Schmalstieg et al. [22] use Augmented Reality (AR) for exploring flow visualizations.

We can achieve immersion in many different ways. We can be immersed in a book, because the story is engaging. We can be immersed with a task (such as writing) because our attention is fully on that topic. We can also be immersed in a virtual world, especially when using a HMD. In this regard we encourage the use of a wider set of technologies and we do not restrict ourselves to the use of, say, HMDs. The ultimate goal is to provide interfaces that are more natural, integrate many senses and can use the body (such as through gestures) to interact.

There maybe several visions. We can imagine a student walking with a hand-held screen (or indeed a mobile HMD) through a castle, interacting with avatars of people who lived there. Additional perceptual queues, such as the sound of a blacksmith forging weapons in the background, or the smell of cooking fires nearby can enhance the sense of immersion. To enhance the informational view, the student sees data about the people they encounter; for instance their position in the hierarchy of the social structure of that time. Likewise, we can imagine groups of students, collaborating in a virtual space, while sitting at their (physical) desks, setting out historic battles and managing their armies through tangible interfaces, with data overlayed on the virtual battlefield (e.g., comparing army size, or types of arsenal).

Inevitably, there are many questions on how to realise these visions. For instance, how can we successfully integrate data visualization with MR? What exisiting visualization techniques are useful in a MR context, and which (if any) new affordances in data visualizations can be achieved via immerson? How can users interact with the MR content and control parameters of the system to see different results? How can we demonstrate what we know (fact) and what experts have suggested? How can we manipulate and render terabytes of data from laser-scanned sites at interactive speeds?

We have been working towards some of these goals in our heritagetogether.org project, where we have focused on prehistoric sites including standing stones, burial chambers, dolmen etc. We use citizen science, such that members of the public can take photographs of these sites and upload them to a server; the server then organises the images, and 3D models are created using a process of photogrammetry. The resolution of the models is automatically reduced, such to make them render quickly on a webpage. We display the data on in many alternative ways [12, 13], including on the web using X3D models and X3DOM. We integrate the 3D models with site-numbers, such that users can load and discover additional information from related archaeological databases (including the Coflein database). We have developed a table-top interface to display and manipulate the 3D models through tracked, 3D-printed, tangible objects (see Figure 2). Finally, we have developed a Virtual Museum to allow users to explore the models in a museum metaphor (see Figure 3).

4 Deep Maps

One notion, popular in Digital Humanities, that lends itself nicely to Immersive Analytics (and particularly MR) is Deep Maps [1, 2]. There are various definitions of a Deep Map; for us it is a collection of interconnected and intertwined, context and location dependant data that can help us build a narrative, specific to a place (place being space with context [21]). The concept of a deep map comes from the book PrairyErth by author William Least Heat-Moon [6]. In our context, a deep map integrates stories, narratives, sayings, maps, images, photographs etc. and develops a deep narrative about a cultural heritage place. It is 'deep' because it includes a wide range of archaeology-related data, stories, memories, artefacts, sayings, facts, surveys, maps, 3D models, photographs (etc.) and it encourages users to perform active investigation. It is a 'map' because it focuses on a small area of the earth, a place. We do note that 'grounded visualization' is a similar concept to deep maps e.g., [10] where solutions integrate GIS with multiple views [18].

Towards developing interfaces for deep maps, we have started to investigate relative concepts. Work by Williams and Roberts [24] in collaboration with Gwynedd Archaeological Trust, looked at developing new ways to explore the heritage information. While still in its early stages of development, the idea has demonstrated that there are different visualization forms that are suitable for different data types. Moreover, a series of research questions were highlighted: How can we develop heritage exploratory interfaces that include expert tacit knowledge? How can we make this tacit knowledge more explicit? How can we integrate artefacts with the location information? How can we display the small data (e.g., finds) alongside, and in-context, with the larger physical data (e.g., site data). How can memories and sayings be included with the site? How is it best to integrate survey, map and multi-spectral sensory data? How can we integrate uncertain information of sketches and plans, which in turn could be used to propose different hypotheses. Finally, how can we integrate hypothesis driven approach with facts?

As aforementioned, more and more heritage data is being stored in databases and becoming available to researchers. This is both thanks to

Open Data initiatives and funding bodies, which insist that data from publicly funded projects are actually publicly available. However we still have a long way to go. Even now, the data is not easily available to the public. While query tools have been created to retrieve the data, they are often difficult to use, and only provide limited functionality. For example, in Wales, the Royal Commission has an online searchable database Coflein (www.coflein.gov.uk) and the Welsh Archaeological Trust's online HER Archwilio (www.cofiadurcahcymru.org.uk/arch) stores scheduled monuments and other finds. While the tools plot the finds and artefacts on maps, few other visualization techniques are included. Moreover, these tools are not interactive, merely returning the results from a search query. Few heritage systems allow dynamic querying, brushing, and other information visualization functionality. Overall, not only is the availability of heritage exploratory tools far behind other fields (such as business information systems) in their capacity and capability of visual analytics, but their application and usage is also lacking. The use of GIS techniques may be powerful and widespread, however it is not generally accessible by many users. With Immersive Analytics and Deep Maps, our aim is not only to make exploratory tools more available, but to push the vision even further.

5 Summary & Next steps

Archaeologists need to make informed decisions based on data that is both complex and beset by uncertainty. Providing (and accessing) such data openly, mapping it using interconnected methods, using immersive techniques to collaboratively visualize it and interact with it, and, finally, determining, saving and revisiting exploration paths and spatial narratives. should help scientists to transform the domain. In addition, these visions should help the public to interact with the data through new technologies in compelling and novel ways, and to find out more about the information. To achieve these goals, however, we believe further research needs to be achieved as follows:

- **Open data**. We need to get to a stage when the heritage data is free to access, easy to explore, permanently available, not only to experts but to the general public, and linkable to other datasets.
- **Sensemaking & Visualization**. Users need better sensemaking tools. The goal of deep maps is to enable knowledge to surface, be correlated with other (often diverse) data sources, and enable users to make sense of this information. It should allow history trails, argumentation, storytelling, real data to be visualized alongside interpreted information.
- **Multiscale Data & Visualization**. Data needs to be stored at high quality, but techniques need to be developed to provide data at different scales, resolutions and sizes. We need fast access for the public, but then able to compare data at high resolution.
- **Collaboration**. Collaboration research is required to allow people to learn, collaborate and argue over interpretations, in the heritage domain – whether this is achieved, through immersive techniques, deep mapping exploratory techniques, or otherwise.
- **Infrastructure**. We need better visualization and data analysis tools in the heritage domain, to support collaboration, easy presentation and manipulation of data, clear indication of quality and data provenance.
- **Immersive Displays & interactive technologies**. More research is required to investigate novel immersive techniques, MR and VR technologies for the heritage domain. Along with displays, interaction is a key to understanding the data. Research should focus on enabling more senses to be used in a mixed and immersive environment.

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