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Alternative Representations of 3D-Reconstructed Heritage Data

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By collecting images of heritage assets from members of the public and processing them to create 3D reconstructed models, the HeritageTogether project has accomplished the digital recording of nearly 80 sites across Wales, UK. A large amount of data has been collected and produced in the form of photographs, 3D models, maps, condition reports and more. Here we discuss some of the different methods used to realise the potential of this data in different formats and for different purposes. The data are explored in both virtual and tangible settings, and – with the use of a touch table – a combination of both. We examine some alternative representations of this community-produced heritage data for educational, research and public engagement applications.

CCS Concepts: •**Applied computing** → **Archaeology; Digital libraries and archives;** •**Computing methodologies** → **Computer graphics;**

Additional Key Words and Phrases: Automated photogrammetry, crowd-sourced data.

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1. INTRODUCTION

Over 2,500 megalithic monuments, including passage graves, cairns, portal dolmens and standing stones have been identified by archaeologists across Wales, UK. Although the existence of these sites has been recorded, many of the records are decades old and are for sites which have not been recently visited. Many factors are threatening the sites, such as general weather damage and changes in the local landscape for urban and rural development, but it is not feasible for a single archaeological team to visit and survey the sites due to their large number and geographic spread.

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Obtaining a comprehensive digital photographic record of a site is now standard practice when recording archaeological sites. With a sufficient number of photographs exhibiting a significant overlap between each, it is possible to employ automated photogrammetry and image-based techniques to create virtual 3D reconstructions of recorded sites [McGlone 2013; Linder 2009]. Many software solutions exist, and as such the practice of photogrammetric reconstruction has become a standard method of recording for many sites.

While traditional recording techniques, such as those carried out with a GPS or total station, must be performed by trained archaeologists, a digital photographic record can be taken by anyone. With the rise in popularity of citizen science and crowd-sourcing approaches, several ongoing projects allow amateur enthusiasts to contribute to the recording of both tangible and intangible heritage, and at different stages of the process, such as MicroPasts [Bonacchi et al. 2014], the People's Collection Wales [Tedd 2011] and the Hillforts Atlas project (http://www.arch.ox.ac.uk/hillforts-atlas.html).

The HeritageTogether project seeks to co-produce records of the megalithic monuments of Wales with local communities, and is exploring alternative methods of representing the data created as part of the project. Crowd-sourced images have been used to produce 3D-reconstructed heritage via photogrammetric means. The photographs themselves form a useful dataset for research, and are made available through a gallery system. As part of the project, a large number of new maps and condition reports have been created as a means to guide the general public to local sites of interest. HeritageTogether is unusual in providing both academic and public outfacing aspects. This dual nature has required the project to present the data in a number of alternative representations that target different audiences and situations [Roberts 2007].

This paper opens with a project overview, covering general aspects of the HeritageTogether research project. Section 3 discusses the types of data the project has both received and produced during its course. Section 4 examines the different methods and types of visualisations the project has utilised for research and public engagement. This is followed by a discussion in Section 5, where each of the techniques are examined and their strengths and weaknesses are reviewed.

2. PROJECT OVERVIEW

HeritageTogether (http://heritagetogether.org/) is a project that aims to create 3D models of megalithic monuments (such as standing stones and burial chambers) in Wales, UK, from crowd-sourced images. Members of the public upload their photographs of the sites to the project website. Models are created using an open source automated photogrammetry work flow (see Fig. 1) that has been deployed on a server. Sections of this paper have been previously presented in [Miles et al. 2014a; Miles et al. 2014b; Ritsos et al. 2014].

The following sections describe the project work flow as shown in Fig. 1, giving detail on the processes occurring during the different stages: fieldwork (Section 2.1), website (Section 2.2), automated photogrammetry and model creation (Section 2.3), uploading the models to the website (Section 2.4) and uploading the data to the research portal (Section 2.5).

2.1 Fieldwork

Contributors must begin by selecting a site to capture. Involving local communities in the project potentially holds the benefit of local knowledge – people local to the area are more likely to know the locations of sites, and to know which are readily accessible. They may also know local land owners in person, being able to seek permission to access sites on private land more easily. For those wishing to visit sites outside of their local area, or who have less knowledge of a site they wish to visit, information and maps are available on the project website.

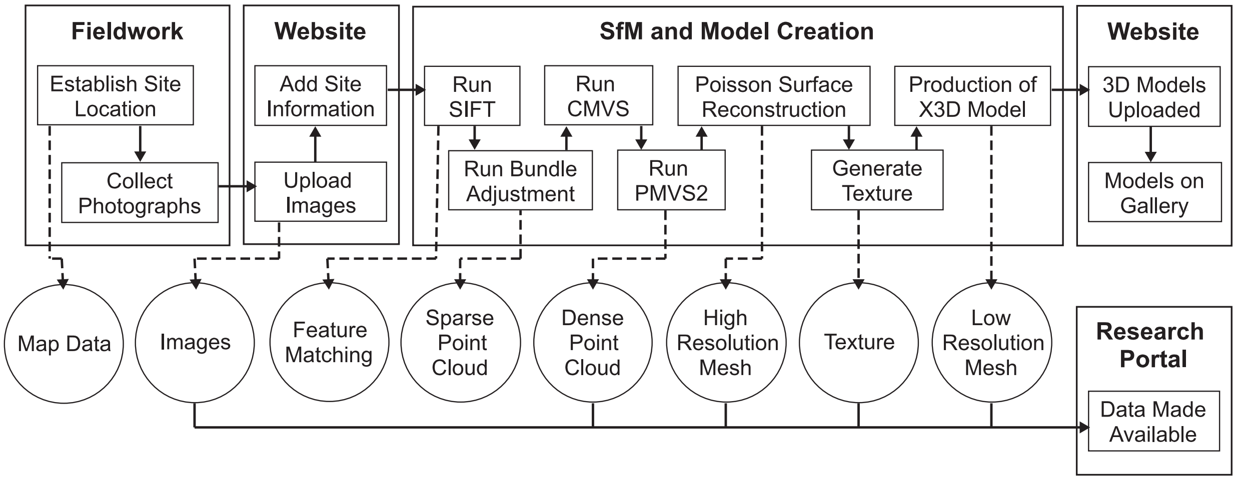

Fig. 1. The work flow of HeritageTogether, from the initial photography fieldwork to the model creation and distribution via the website and research portal. Processes are contained within rectangles, data produced from the processes are contained within circles; data is produced from the processes marked with the dashed lines.

Upon visiting the site, the contributors take photographs. Contributors are not expected to possess any knowledge or expertise in archaeology or the process of creating models using image-based methods, therefore guidance on best practice for taking photographs for the purpose of reconstruction is provided on the project website.

2.2 Website

The website is divided into four distinct sections: an information hub, a gallery, a forum and a research portal. Each is powered by a content management system, in order to allow all members of the project to easily add information: WordPress (https://wordpress.com/) for the information hub, Coppermine Photo Gallery (http://coppermine-gallery.net/) for the gallery system, Simple Machines Forum (http://www.simplemachines.org/) for the forum and the Comprehensive Knowledge Archive Network (CKAN) (http://ckan.org/) for the research portal. Contributor's images can be easily uploaded to the image gallery and viewed as an album. Users are also encouraged to share their experiences of visiting sites and taking photographs on the forum.

The forum has proved to be an important section of the website for both the general public and the research team. By taking part in discussions on the forum, it has been possible for members of the public to ask questions of the researchers on the project, from both the archaeology and computing perspectives. Being able to engage in discussion with the public through the forum has allowed the team to refine the guidance and resources on the information hub throughout the project based on feedback and questions asked.

2.3 Automated Photogrammetry and Output

Once enough photographs of a site have been uploaded, either by one contributor (perhaps over several sessions) or many contributors, the photographs can be processed to create a model. The number of photographs required depends on the site in question: the photographs must capture the surface of the site and have enough overlap to be matched; this could mean 20 photographs are enough for a single standing stone, but hundreds may be required for a complex burial chamber. Fig. 2 presents a standing

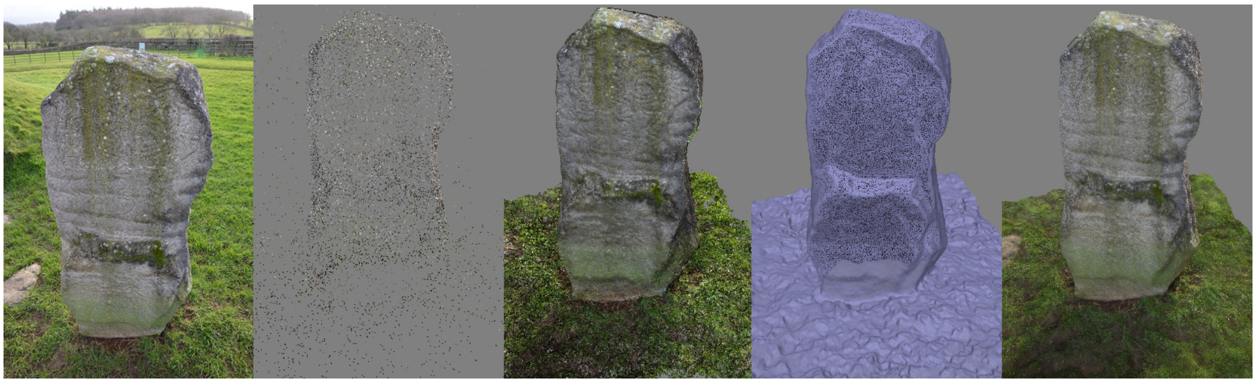

Fig. 2. A standing stone outside the Bryn Celli Ddu chambered tomb in Wales; here used as an example to demonstrate the different processing stages from left to right: photographs, sparse point cloud, dense point cloud, mesh, and final textured model.

stone at the site of Bryn Celli Ddu, a chambered tomb on the Isle of Anglesey in North Wales, during the different processing stages used to reconstruct the final model.

To perform the processing, a member of the administration team selects an album. Images are matched using VLFeat, an open source implementation of the Scale Invariant Feature Transform (SIFT) [Lowe 1999; Vedaldi and Fulkerson 2010]. Matched features are then used to create a sparse point cloud using Multicore Bundle Adjustment [Wu et al. 2011]. The sparse cloud is processed into a dense point cloud in clusters using the Clustering View for Multi-view Stereo (CMVS) [Lazebnik et al. 2007; Furukawa et al. 2010] and Patch-based Multi-view Stereo (PMVS2) algorithms [Lazebnik et al. 2007]. Poisson Surface Reconstruction [Kazhdan et al. 2006] is used to produce a mesh from the dense point cloud, and a texture is produced from the camera images.

The entire work flow is run sequentially using a batch script to execute each algorithm. Once the dense point cloud has been created, a Meshlab (http://meshlab.sourceforge.net/) script executes the Poisson Surface Reconstruction and creates a texture from the images [Cignoni et al. 2008].

2.4 Uploading Models to the Website

The models produced are large, and must be decimated and converted to X3D to be made suitable for the web. The models are decimated using Quadric Edge Collapse Decimation [Garland and Heckbert 1997], reducing the mesh to a target of 8,000 faces, while maintaining the original texture; this often produces models under 1 megabyte in size. The models are converted to the X3D format using Meshlab, then the quality is checked by an administrator. Because the purpose of the project is primarily to engage the public with their own local history, the model quality assessment is based on the visual aspects of the model. No statistical analysis has been performed to compare the models produced by members of the public to models produces by experienced archaeological surveyors because no sites have yet been photographed by both parties.

Once models are prepared, they are uploaded directly to the website gallery and are displayed using the X3DOM [Behr et al. 2009] JavaScript framework, which is embedded on the gallery pages. X3DOM runs server-side, allowing X3D scenes to be displayed without requiring the user to download any plug-ins, providing the browser supports WebGL.

2.5 Research Portal

To maintain the open nature and transparency of the project, a research portal was produced. Based on the CKAN back end, the HeritageTogether Research Portal (http://heritagetogether.org/research) contains archived copies of the data produced over the course of the project. This archived data is held in collections relating to different types of data produced, from raw point cloud data to the final 3D model files. The archive system is based upon open source licensing, and as such all of the data contained within is freely available to download for non-commercial uses. This platform provided the project with a long term storage solution, following both metadata and data archiving standards, but also enabling the data to be utilised or re-analysed by future academics and research projects.

Once photographs have been uploaded and processed into models, they are packaged into zip files and made available through the Research Portal. Collections are divided by site; each site contains an entry for photographs, X3D and Wavefront Object (Obj) models. Photographs are zipped per contributor and session, while model files are zipped with the corresponding texture and material files.

The resolution of the models uploaded to the website gallery is reduced in order to allow instant viewing through the X3DOM viewer, but this reduction in resolution is not desirable for those wishing to use the models for research purposes; the models are therefore also uploaded at their original resolution in Obj format. Some sites have been uploaded both as Obj models and point clouds; at their original resolution, these often exceed 50 megabytes per model.

The photographs uploaded by contributors range from 5–20 megapixels, and originate from a number of different types of cameras including digital point-and-shoot cameras, DSLR cameras, and even tablets. The generated models were produced with medium resolution settings to allow the server to manage the potentially heavy access loads; this resulted in models with an original resolution of between 50,000 and 300,000 faces. The large variation in the number of faces is due to the variation of the models, from physically small sites with a single standing stone made with less than 30 photographs, to physically large sites with multiple burial chambers created from hundreds of photographs. Given that the photographs are available to download at their original resolutions of 5–20 megapixels, it would be possible for researchers to use the photographs to create new, higher resolution models, if the resolution provided is not sufficient, or as image-based reconstruction software improves.

3. DATA PRODUCED BY THE PROJECT

The data produced from the HeritageTogether project includes: the photographs taken by members of the public; the 3D models of sites produced by those photographs; site information volunteered by contributors and the geo-location data gathered to create maps (see Fig. 3).

Between January 2014 and February 2015, HeritageTogether has received over 13,000 photographs of prehistoric sites. After analysing the photographs that have been uploaded to the site it is clear that a variety of cameras, ranging from lower-quality mobile phones to high-quality Digital SLRs, have been used. Some information can be gathered from the EXIF data contained in the images, but cameras are not calibrated by the users [Fraser 2013], and little information is available for 3D reconstruction.

Making the data accessible to as many people as possible is a primary goal of the project, so the 3D models were all created initially in Obj format, as it is a common 3D format, while the models are displayed on the web gallery in X3D format, as it is a common format for 3D data on the web.

Site information has been volunteered by some of the contributors, who have offered details of their visits as well as advice for others on the HeritageTogether forum. This information is valuable to other members of the public interested in visiting the sites, and to archaeologists to provide basic (but recent) reports on the condition of the sites.

Maps displaying the locations of the sites were created using GPS coordinates gathered from publicly-available datasets maintained by the Royal Commission on the Ancient and Historical Monuments of Wales (RCAHMW, http://coflein.gov.uk). The maps show the locations of over 2,500 prehistoric sites across Wales to approximately 3-metre accuracy (see Fig. 3). Because the project is asking members of the public to visit sites, some of which are difficult to locate, it is important to provide accurate site

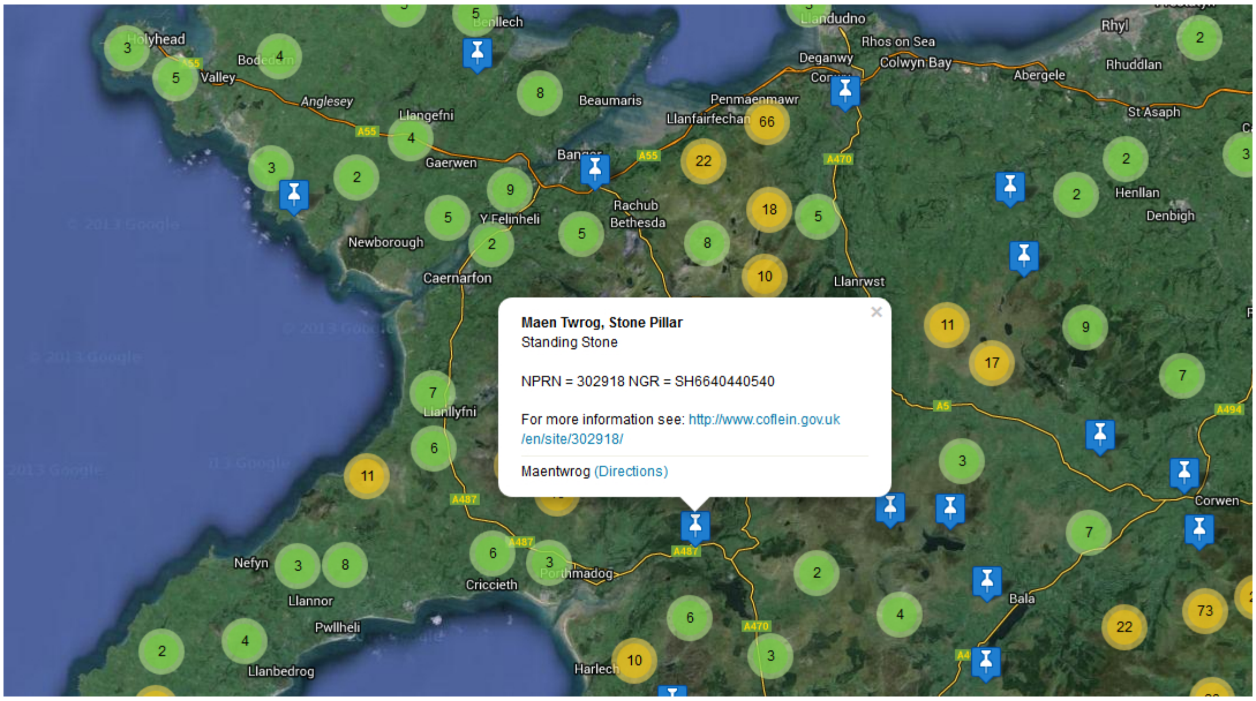

Fig. 3. Section of a map displaying the sites of interest to the project across North Wales; sites are clustered into groups dependent on the zoom level.

location data. Due to data protection, we are unable to provide public access to land ownership data, and members of the public wishing to visit sites are recommended to ensure any sites they wish to visit are on open access land, or to obtain land-owner's permission.

4. METHODS OF REPRESENTING AND USING THE HERITAGE DATA

Although the different types of data produced by the project call for different methods of representation, the purpose of these representations and visualisations falls into two categories: research and public engagement.

The data can be used for research purposes by archaeologists and computer scientists. The archaeologists can interpret the data to try to understand the meaning of the monuments as objects in isolation but also as monuments within their surrounding landscape. Computer scientists can investigate the datasets themselves, analysing the metrics and visual renderings of the 3D model.

Public engagement is an important and complex part of heritage work, which requires careful balancing of a broad spectrum of activities aimed at audiences of many ages, backgrounds and personal interests. For example, children enjoyed using the interactive touch table (Section 4.5) whereas the adults responded well to the workshops and more formal presentations of the research work. To provide for these wide-ranging audiences, material for each group has been considered.

To engage directly with the public, a number of open days and workshops were held throughout the project. Open days and introductory workshops provided an excellent way to engage with local communities, to give them not only ideas about the project and local sites of interest, but also some basic skills in performing photogrammetry for archaeological recording. Introductory workshops provided basic skills training in the methods of photogrammetry, illustrating how the data is processed

Fig. 4. Different methods used to represent the HeritageTogether data.

and final 3D models are produced. These workshops were aimed more at adults interested in heritage recording due to the complex nature of photogrammetry methods. The sessions focussed on two different aspects of the process: the photography, and the data processing. Open days were aimed more at giving wider examples of our research to a more general audience, with different activities produced for children and more text-based information for adults.

Being reliant on crowd-sourced data, the HeritageTogether project had a focus on public engagement, using the data already collected to create new visual and tangible exploration tools to inspire more members of the public to contribute data to the project. The tools developed ranged from web-based and virtual systems to tangible and mobile methods for use during the engagement activities. Fig. 4 outlines the different representations explored by the project team. In the following sections, each of these representations will be described and their suitability discussed.

4.1 Model Comparison Tool

The task of directly comparing different sites is of interest to archaeologists. A visualisation tool has been prototyped to allow the brief, visual comparison of two sites using the model data created by

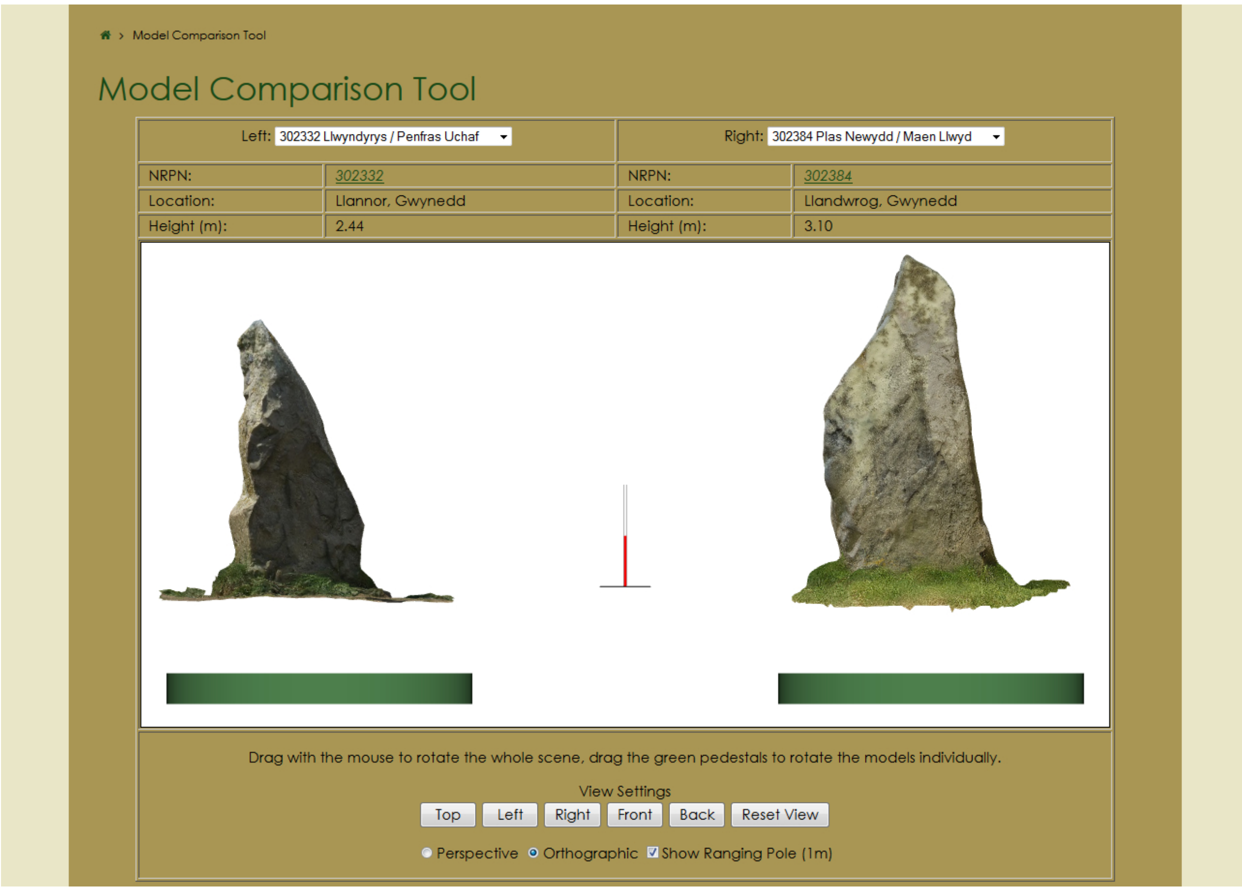

Fig. 5. The model comparison tool with two models displayed using orthographic projection.

HeritageTogether (see Fig. 5). The model comparison tool is available as a resource on the HeritageTogether website for users to compare two of the models (http://heritagetogether.org/?page_id=2944).

For the sites to be directly comparable, the models are first oriented correctly and scaled to approximate the size of the real sites. Scale data was obtained from RCAHMW site reports in the National Monuments Record (available on their online data archiving system, Coflein), and models were scaled manually using Meshlab. Site scaling was approximate, due to the complex shape of the models and the site report measurements often being estimated by archaeologists.

The tool is web-based and uses X3DOM to display the models. Two sites can be selected for comparison from drop down menus; when a site is selected, the National Public Record Number (NPRN) individual identifier is displayed, along with location and height data. Each model can be rotated individually using the green pedestals, and the scene can be rotated and manipulated as a whole. Different default viewpoints can be selected using the buttons below the model viewing window, and projection can be toggled between orthographic and perspective; an archaeological ranging pole is displayed in the centre to provide a sense of real-world scale.

Fig. 6. A set viewpoint displaying the whole mound and an annotation, in this case the description of the site.

Fig. 7. A set viewpoint looking down from directly above the mound, showing the diameter to be approximately 26 metres.

4.2 Interactive Documents

Since the release of the Portable Document Format (PDF) 1.6 standard in 2004, PDFs have supported the embedding of 3D content in the Universal 3D (U3D) format. Adobe Reader – since version 7, which accompanied the release of the PDF 1.6 standard – allows the viewing and manipulation of the 3D content, while not requiring any additional software to render the model. Reader also provides the user with a '3D toolbar', with tools to examine the model by manipulation (zooming, rotating and moving the model), add 3D annotations that are fixed to a point on the model and make measurements of the model, providing the unit to real-world measurement ratio is known. The user can choose from a variety of rendering options for the model, the scene lighting and background colour; it is also possible to view the scene using orthographic or perspective projection.

These interactive documents can be used not only as a way to explore the models of the sites, but when annotated by experts, they can also be used as educational material. An example is provided in Figs. 6 and 7, which display an interactive PDF for the burial chamber of Bryn Celli Ddu.

4.3 Tangible Models

As part of the project's school outreach program, 3D printers were used to produce tangible models of some of the standing stones (see Fig. 8). These tangible models served as excellent demonstration devices during workshops and open days, to illustrate the capabilities of the process of photogrammetry to members of the public.

One of the more interesting aspects of the tangible modeling is the ability to change and redesign the original model to make them more engaging for school children. For example, the model of the standing stone at Bryn Celli Ddu was turned into a simple puzzle set, as shown in Fig. 9. The 3D model was sliced into a number of pieces of different shapes and sizes with a central pillar and base to support the model during construction. The children could rebuild the standing stone, placing each of the sections onto the supporting pillar. The 3D puzzle proved very engaging for older children, but was unfortunately somewhat difficult for the younger children for whom the original idea was conceptualised.

As part of the educational aspect of the project, work was carried out to create papercraft 3D models of each of the sites (see Figs. 10 and 11). These papercraft models were made as part of the outreach

Fig. 8. 3D printed miniature standing stones, using the models created by the project.

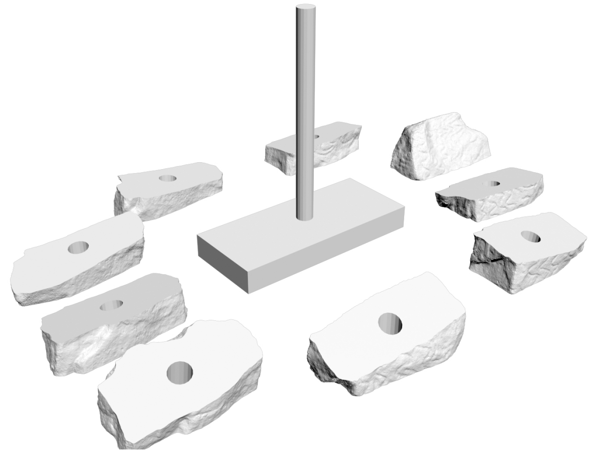

Fig. 9. A puzzle created from the model of the Bryn Celli Ddu standing stone.

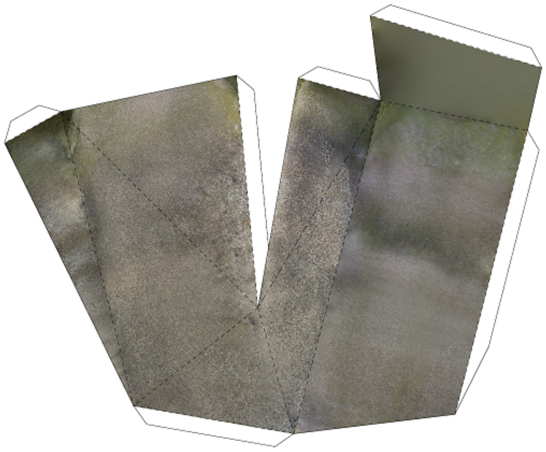

Fig. 10. A simple papercraft model of Bryn Celli Ddu generated using Pepakura Designer.

Fig. 11. Three of the completed models: in the centre a model of the Llanfechell stone appears complex due to the textures, while the left and right models demonstrate two versions of the Bryn Celli Ddu model.

program to encourage children to take part in the creation of new models of standing stones. To produce the papercraft models, the original 3D model of the site was heavily decimated using Quadric Edge Collapse Decimation, maintaining the original texture but only around 6–20 of the original polygons. This results in very abstract models which vaguely resemble the original models. The Pepakura Designer (http://www.tamasoft.co.jp/pepakura-en/) software package was then used to unfold the decimated models onto a flat surface and add numbered tabs to direct the user on how the model should be folded and glued (see Fig. 10). The papercraft models are available to download on the outreach section of the project website (http://heritagetogether.org/?page_id=2716).

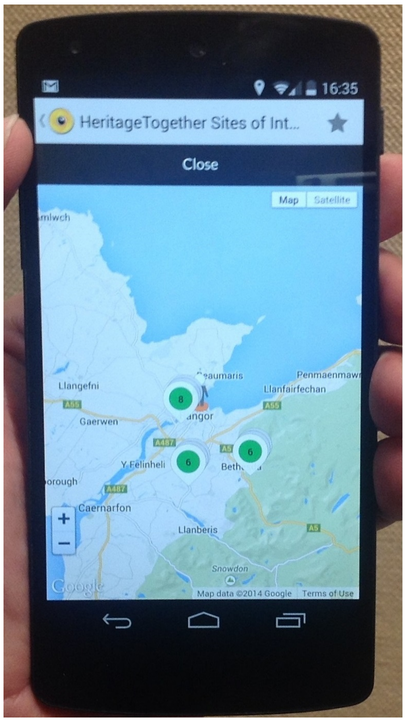

Fig. 12. Top-down map view showing sites on a map.

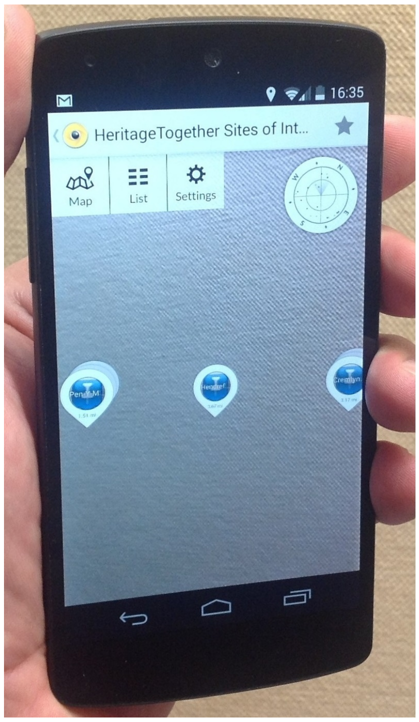

Fig. 13. Relative map view showing the sites in their orientations relative to the smartphone.

Fig. 14. Augmented reality Awe.js demo displaying a model at a specified GPS location.

4.4 Mobile Applications

Augmented Reality (AR), the enrichment of physical reality with interactive, spatially registered computer generated objects [Azuma 1997], is widely used in cultural heritage applications, e.g., Zoellner et al. [2009], Choudary et al. [2009]. In our project, the Wikitude AR SDK (http://www.wikitude.com/) was used to create an AR map, accessible on handheld devices, using site location data from the Maps Marker Pro plug-in for WordPress (https://www.mapsmarker.com/); the latter was used to display a map with site locations on the project website. The Map offered both a basic top-down view (as shown in Fig. 12), and a view, relative to the user's actual position and orientation of the handheld device, placing the map markers *in situ* on site locations (as shown in Fig. 13). Information about each site and distance from current location is also displayed.

An additional AR application was implemented, displaying simplified versions of the 3D models, created from the project, *in situ* [Ritsos et al. 2014]. Using the Augmented Web Experiences API (Awe.js, https://github.com/buildar/awe.js/), models were linked onto the GPS coordinates of the actual site, so that the model produced could be compared to the real site (see Fig. 14). Awe.js uses WebRTC, WebGL and sensor APIs to display the AR content on a standards-based browser, (Chrome, Firefox, etc.), eliminating the need for a dedicated AR browser.

4.5 Touch Table Applications

The Samsung SUR40 is a touch-screen table based on Microsoft PixelSense technology, which contains a full PC to allow stand-alone operation in museums and similar settings. An array of infrared lights is

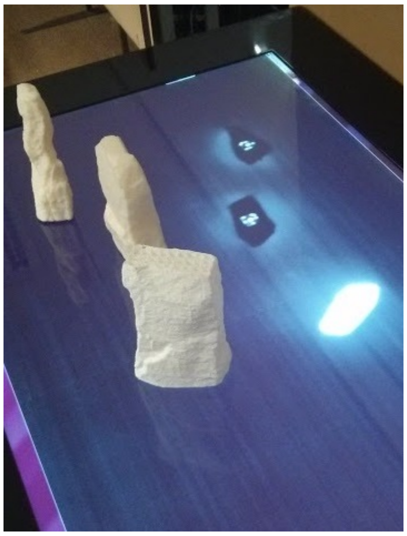

Fig. 15. Tangible models on the Samsung SUR40 multi-touch table: the black foam bases absorb the excess infrared light and highlight the byte tag.

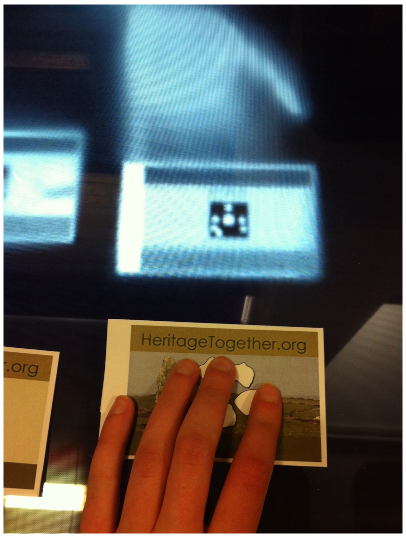

Fig. 16. Samsung SUR40 multi-touch table application demonstrating the input received from the tag cards.

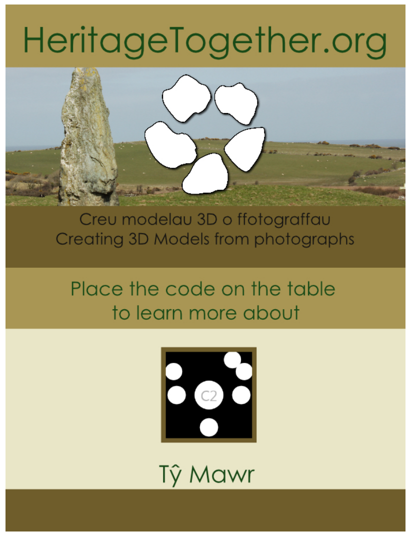

Fig. 17. Card with byte tag to use on the Site Explorer application.

projected at the screen from within, with reflections on the surface being interpreted as touch activity. This allows most objects placed on the surface of the SUR40 to be used as interaction devices. The SUR40 is capable of reading a set of visual tags to cause events and interactions; these 'byte tags' are limited to a set of 256 individual tags, as each tag stores an 8-bit value (see Figs. 15, 16 and 17). The reflective properties of an object to be used as an interaction device must be considered however. For instance, when using the printed miniature stones with byte tags as tangible interaction devices, the white plastic caused the light to scatter around the edges of the tag, making it difficult to read. To counter this, the models were fitted with black foam bases to absorb as much of the light as possible and highlight the tag (Fig. 15).

Two exhibitions featuring the SUR40 were held for the general public at the Aberystwyth Arts Centre, UK, featuring an application called the 'Site Explorer'. Each exhibition was a month long, with one running through April and the other through August 2014.

The base application remained the same for both exhibitions, but featured different sites. The purpose of the application was to disseminate information about the project to the general public, to provide information and educate users about sites and encourage them to take part in the project.

Each featured site was presented on a template window (see Fig. 18); the window featured a series of 'scatter' items that could each be moved and manipulated individually on the screen to encourage multiple users to interact with the application at the same time. The items are initially scattered across the screen space at random:

—an information card containing the location and a description of the site;

—an interactive map showing the location of the site on satellite images;

—a set of photographs of the site from the HeritageTogether gallery;

—two QR codes, one leading to the HeritageTogether homepage, one leading to the site's entry on the Coflein website;

Fig. 18. Site Explorer application developed for the exhibitions.

Table I. Usage Statistics for the SUR40

	Exhibition 1		Exhibition 2	
Uses per Day	Mean	Total	Mean	Total
Monday	20	100	17	34
Tuesday	13	53	15	29
Wednesday	15	58	22	67
Thursday	16	62	15	44
Friday	18	72	13	38
Saturday	73	293	-	0
Sunday	8	32	-	0

Mean and total number of uses of the information applications per day on the Samsung SUR40 multi-touch table throughout two month-long exhibitions.

—a button that switches the language of the application between Welsh and English; and

—a button which leads to a new window displaying an interactive 3D model of the site.

Three types of 'interaction card' were produced for the exhibit, each featuring a different site (shown in Fig. 17). The byte tags on the rear of the cards activated the different information pages. Visitors were able to use the cards as another means to interact with the table, then take them away as a reminder of the project.

Usage statistics for the table were captured to give a basic impression on the impact of the exhibitions, with a summary shown in Table I. The site information pages were accessed an average of 23 times a day during the month of the first exhibition. Usage ratings fluctuated with the working week, with peak access ratings occurring on Saturdays and low access ratings occurring on Sundays. The applications were used for a combined total of 47 hours throughout the month. With 47 hours of usage across the 667 times the applications were accessed, each session lasted an average of 4.2 minutes.

During the second exhibition, some issues with the SUR40 device resulted in the table not being active for a portion of the exhibition; the system was also not active during the weekends of the second exhibition. The five site information pages were accessed a total of 212 times throughout the month – 16 times per (active) day on average. The total of 12.6 hours of interaction results in an average session length of 3.5 minutes. Despite technical issues preventing the exhibition from running for the full length of the month, the access figures show that the second exhibition had comparable average numbers of sessions to the first exhibition.

The exhibitions provided the team with an opportunity to demonstrate some of the models created as part of the project using a touch-table as an interface. This was of particular interest to children, who were found to enjoy playing with the table a great deal.

5. DISCUSSION

During the ongoing collection and processing of crowd-sourced images, we have investigated several methods of representing the data produced. Methods were developed for use primarily in public engagement, though research applications were also considered. Some representations proved popular with users, while others did not perform as well as was hoped for. In this section we will discuss each method in turn, critically examining the responses of users, considering which were successful and which were not.

5.1 Project Website

Table II holds the visitor statistics gathered for the website since it was launched in January 2014 up until the time of writing in February 2015. The site has been broken into the sections described in Section 2.2, each of which are governed by a different content management system (CMS).

The information hub, built using the WordPress CMS, attracted a large number of visitors, who spent a great deal of time (nearly an hour and a half on average) browsing the available information across a large number of pages. The gallery was accessed by a smaller number of visitors, but had a much higher return rate, likely to be a result of contributors returning to upload more photographs. The access statistics for the forum reflect the constant attempts of spam bots and other fraudulent services to register for the website. While the use of a well-known CMS (Simple Machine Forums) for the forum may have resulted in the site being identified as target for spam activity, the community developing the open source forum framework is dedicated to updating the system regularly to counter developing spamming techniques.

Due to the crowd-sourced nature of the project, HeritageTogether adhered to an open data policy. All data uploaded by the team or contributing users and created for the project is available for any individual to download and use for non-commercial purposes via the Creative Commons Attribution-NonCommercial 4.0 International License (CC BY-NC 4.0).

Website visitor statistics (Table II) show that the research portal had a significantly smaller number of users to other portions of the website. This is thought to be for two main reasons: the first is that the research portal was added to the website much later than the other three sections (October 2014); the second is that it caters to a more specific audience. Statistics from the CKAN system indicate that 35 unique users have downloaded files, of which 30 were from university registered domains. Although academics have downloaded this data, thus far we have no examples of the data being used to produce any additional research.

Table II. Visitor Statistics for the Website

Website Section	Information Hub	Gallery	Forum	Research Portal
Total Visits	5401	1094	109373	107
Unique Visitors	3307	437	108060	102
Page Views	22719	10396	311160	406
Average Visit Duration	01:27:25	00:09:09	00:01:23	00:01:50
Percentage of Repeat Visitors	2%	30%	$<0.5\%$	7%

Website visitor statistics from January 2014, when the website was first launched, to February 2015. The total number of visits and page views by the unique visitors are given for each section of the website, along with the average visit duration and the percentage of visitors who returned to the site versus the influx of new visitors.

5.2 Model Comparison Tool

The model comparison tool was created to enable researchers and the general public to visually compare the 3D models of sites in our collections, allowing users to engage with the data, comparing the variety of shapes and sizes of the sites. The tool provides an additional frame of reference to the models by rendering them in comparable sizes, but it may still be difficult to imagine these comparative measurements adjusted to real-world size; the ranging pole aims to provide some context to real-world measurements.

As a mechanism for performing research, the model comparison tool is limited by the use of the low-resolution models. The tool was created as a prototype for visual examination of the data, but would need to incorporate the full resolution models for it to be a useful tool for researchers. The low-resolution models were initially used to ease the development of the web-based application; the application could be extended to support higher resolution models, giving users the option to select the resolution they desire. The approximate scaling would also be an issue, though it would be more complex to address. While it would be possible to offer a target of known size for members of the public to print and place within the photographed scene, the photographs already contributed will not contain the target. We have not yet conducted a test phase with professional archaeologists or the general public to analyse its usability.

5.3 Interactive Documents

The interactive documents were useful as teaching tools for including site information with the models for added understanding of the data. The documents were not difficult to create, but proved to be time-consuming to populate with site information and fixed viewpoints. While the software enabling the creation of 3D PDF files has not developed a great deal in recent years, the prevalence and ubiquity of PDF as a format allows dissemination of the models to members of the public in a common format, and does not require them to obtain any specialist modelling packages to view the 3D content. As with the model comparison tool, the interactive documents have not undergone any evaluation at this time; as such, the potential of these documents has yet to be fully realised.

5.4 Tangible Models

The 3D printed tangible models proved to be a popular representation. Many of the members of the public who were shown the models during open days and workshops had never seen a 3D printed model before, and they were impressed by them. The tangible nature of the models was effective, especially for the model of the stone at Bryn Celli Ddu: people enjoyed examining the rock art on the model, and feeling the shapes of the spirals and waves.

The two tangible activities were less successful: the 3D printed puzzle and the papercraft models were too complex for the younger children they were intended for. The 3D printed puzzle was enjoyed by some older children, and so proved to be successful for an audience it was not directly intended for.

The papercraft puzzles were found to be too complex even for the adults who tried them, which was unfortunate as many children wanted to try to make them.

5.5 Mobile Applications

The mobile applications described were not made available to the public as they currently remain in the testing phase. The Wikitude mapping application has been taken into the field by project team members who quickly discovered that many of the sites are in areas with poor mobile data network coverage, which rendered the application impossible to use. Currently the application requires a stable data connection to download mapping data, but this issue could potentially be avoided by pre-downloading small amounts of data. A sufficient GPS signal is often available where mobile data networks are not, and it would be possible to develop a full application using the Wikitude SDK (as opposed to hosting the data on the Wikitude platform), as it supports data caching and would be able to guide users based only on GPS data.

5.6 Interactive Touch Table

The touch table was used in two exhibitions at Aberystwyth Arts Centre, the Digital Past 2014 Conference, National Science & Engineering Week (NSEW) exhibitions at Bangor and Aberystwyth Universities, and a number of smaller events. The audiences for the events differed greatly: the conference was host to archaeology academics and professionals, the NSEW exhibitions were school groups and some children with parents, while the exhibitions at Aberystwyth Arts Centre would have been a mix of students and staff from the university, as well as parents and children of all ages attending evening and weekend classes at the centre.

The touch table was accompanied by one or more team members for the conference and NSEW exhibitions, but was left as a permanent month-long exhibit at the Aberystwyth Arts Centre, where it was regularly visited but not permanently monitored. During the time it was accompanied and observed, it became clear that the table was of great interest to children. Unfortunately, their interests were based on the idea of the table being used for games, with many children remarking to team members that the application should be a game instead of information pages. The adults were observed on many occasions enjoying the information given, but were not confident interacting with the touch interface. The table acted as an excellent method of drawing people's interest, as many would visit the stand to use the table when they observed others doing so.

When the 3D printed tangible models were used, both children and adults enjoyed interacting with the models. While the printed cards afforded the same interaction as the 3D printed models, visitors were often confused how to use them. Over 50 cards were taken from the Aberystwyth Arts Centre exhibits, as they were intended for visitors to take as reminders of the project. At the Digital Past Conference, many archaeology academics and professional visited the stand and enjoyed using the table, with several of them commenting to team members at the stand that it provides an excellent engagement platform for introducing younger people to heritage and archaeology.

6. CONCLUSION

Over the course of the project, HeritageTogether has created 3D models for over 80 sites, producing large quantities of visible (models and information on the website) and invisible (ranging from different stages of photogrammetry data to general map data) research data. HeritageTogether has utilised existing open-source software to create a server-side model production work flow, demonstrating the potential for the current technology to expand archaeological and heritage data recording through crowd-sourcing. It is hoped that the use of pre-existing software will encourage other research groups to take up similar work flows.

We have described a number of avenues explored through the data to construct digital models of heritage sites from crowd-sourced imagery. Photographs, reconstructed models and map data form the primary types of data, but from this additional data can be derived and explored. The models of the heritage assets reconstructed using automated photogrammetry have been used in a number of ways to engage members of the public, capture their imagination and involve them in the project and their own heritage. The models can be compared and viewed, on the project website, via 3D PDFs, on interactive applications built for mobile devices and the Samsung SUR40 interactive touch table. The possibility of making the models truly tangible was explored by 3D printing complete models, puzzles to build and papercraft versions to assemble.

Future work in both expansion and evaluation of the tools is planned. The model comparison tool is in an early stage of development; with the ability to load data of different resolutions, it may be possible to examine the tool for research use. The additional issues of the scale and resolution of the models, and the quality of the data produced by inexperienced members of the public will also be examined. Comparison of the models generated by the automated photogrammetry with models of the same sites generated using laser scanning would provide a measure of resolution, while also allowing quantitative and qualitative examination of the data produced by the untrained contributors compared to surveys conducted by trained professionals [Monti-Guarnieri et al. 2004; Alba and Scaioni 2007; Alby et al. 2009; Lo Brutto and Meli 2012; Grussenmeyer et al. 2012; Fassi et al. 2013; Green et al. 2014]. Accurate real-world scale will require a change in the method of data capture to incorporate a target of known-size into the photographs of a site.

There is more potential for using the data for research and public engagement: data is still being produced by the project, and is available via the research portal for anyone to explore and use for further research. The legacy of a project is an important aspect of any research, especially those creating unique datasets; this data has been placed in a long term archive and will also be deposited with the Archaeology Data Service (ADS), providing archaeologists with both a large collection of digital photographs for each of the sites surveyed and a high resolution model. The inclusion of the digital images provide 'raw' data enabling the photogrammetry calculations to be re-performed as the technology and software advances.

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