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Virtual Stonehenge Reconstruction

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Abstract. Visual and spatial technologies are increasingly revolutionising how archaeology and many other disciplines understand the past in relation to the contemporary world. From digital objects to landscapes, through geophysics, geographical imaging systems and the creation of virtual worlds, new technology provides alternative routes to seeing and understanding both past and present [1]. This research paper describes an interdisciplinary art and design approach to rebuilding and visualising phase 3vi of the Stonehenge site for interactive cultural heritage applications in the 21st Century. A 3D digital research team based at the School of Art, Design & Architecture collaborated with music technologists, sculptors and game designers to gather, interpret, re-imagine and digitally re-model historical and contemporary data on Stonehenge to create a virtual 3D reconstruction of Stonehenge phase 3vi. The researchers discuss the range of digital data, tools, methods used in this phase of the Virtual Stonehenge reconstruction project.

Keywords: Stonehenge, 3D, digital, interdisciplinary, art, design, virtual, heritage.

1 Introduction

This research paper presents an interdisciplinary art, design & music technology collaboration, and through this discusses the diverse range of technologies, approaches and methods used within it to re-create the final constructed phase 3vi of the Stonehenge site as a prototype for an interactive educational 3D virtual reinterpretation for cultural heritage. This paper will also demonstrate how designers approach the practical, conceptual and theoretical problems and propose solutions which may contribute to further experimental archaeological research and mobile and real world interactive virtual heritage experiences.

This latest phase of the research originally evolved out from earlier work in the Acoustics and Music of British Prehistory Research Network [2]. Design researchers from University of Huddersfield 3D digital design group were invited to collaborate with Dr. Rupert Till to create a 'structurally complete' and 'accurate as possible' 3D model of Stonehenge phase 3vi for acoustic modelling in a virtual experimental software spaces. Earlier phases in the research project have been presented at TAG 2010, Conference of the Theoretical Archaeology Group; and at Palaeophonics 2011: a live multimedia performance event. Participation at these interdisciplinary archaeology forums has enabled the team to share experiences across disciplines and to demonstrate the interpretative approaches to 3D visualisation of the Stonehenge data.

Photogrammetric recorded digital files of the remaining standing and fallen stones, digital formatted archive maps, drawings, engravings and photographs of the site were sourced and permission for use was granted from the English Heritage and its monument archives [3]. The collective range of artefacts gathered were invaluable to the project in order to retain the authentic conceptual and analytical understanding of the past historical phases of activities at the site and to support the team's integrated collaborative practice based approach to the project.

The researchers applied technologies frequently used in product design, engineering, game design and music technology. The evolving project also required sourcing of new technologies, tools and methods which are presented in the paper in an attempt to highlight the potential of these tools and the benefits of interdisciplinary practice through digital media to cultural heritage practitioners and experimental archaeologists. In particular the main contribution of paper focuses on the three dimensional digital technologies, powerful modelling and aesthetic surface texturing and environmental properties that may be adapted by archaeological and cultural heritage teams to communicate, augment and enhance traditional media approaches for seeing, thinking, recording, analysing and presenting artefacts and historically interpretative experiences at museums, monuments and heritage sites.

2 Contextual Review

Computer graphics can present a deeper and more richly rewarding history by giving a 3D solidity to past places and representation of events, and at the same time act as a repository for the images, words, and objects that together define who we are and how we got here [4]. Use of 3D technologies can also extend and further represent a way to augment the past through alternative interfaces for looking, listening and feeling at heritage sites. Digital models and digital tools are now extensively used to re-create myriad new forms of visual knowledge in scientific research and have increasingly become important tools in a wide range of archaeological project applications, including virtual assembly of relic fragments, virtual collaborative environments, online games used in analysis of economic and political contexts, reconstructions of large-scale spaces, as well as the recording and digital preservation of cultural heritage sites [5].

Digital cultural heritage, cyber archaeology and serious gaming research groups are sharing and combining extensive professional experience with through experimental use of 3D scanning, architectural modelling, crowd modelling, advanced rendering, interactive and augmented reality tools as this approach offers opportunities for bridging the gaps between conservation, digital curation and metric survey by anthropologists, curators, and museum visitors,[6],[7],[8]. Using technology tools and techniques adapted from the video game and entertainment industries archaeologists are now boosting their imaginations and insights through developing virtual worlds [9]. Arnold [10] pragmatically suggests that, "..the big challenge is to deal with the world of cultural heritage and the world of technology. And that...to make documentation in 3D a practical reality you have to make the technologies work better and you have to make practical propositions for normal situations, normal museums, normal archaeological sites and so on". Barrett [11] holds with importance of these shared experiences by reminding us that the remains of ancient monuments are architectural fragments which can; '…allow (researchers) to think through the orientation of the practices which both created that architecture and which were staged within it,'as, something that is aided by a moving, animated, phenomenological, experiential or embodied approach in order to be truly successful, something that is becoming more common both within archaeology, and in other academic disciplines.

Investigations over the centuries have recorded, mapped, modelled and visualised on, in and around Stonehenge and its connected sites. The English Heritage Photogrammetric Unit digitally mapped all the visible external faces of the stones remaining at the monument. Bryan and Clowes [12] discuss their experience of the research process and methods of gathering and processing 3D scan data of individual stones on the site through photogrammetry. In more recent exploratory experiments using 3D digital scanning technologies, Goskar [13] and Wessex Archaeology created a fly through animation for the exhibition titled; Making History: Antiquaries in Britain. Goskar's work uses LIDAR (Light Image Detection and Ranging) data to show 'the subtle features where people once 'worked' the ground into burial mounds, pathways, fields. Community based Heritage Key, and Second life Stonehenge 3D have encouraged virtual communities through immersive experiences that enable public users to choose their own avatar character and virtually visit the monument and its surrounding immersive 3D landscape.

English Heritage [14], have recently commissioned Greenhatch group together with Atkins Mapping and Archaeo-Environment Ltd to acquire a variety of 3D models of stones and landscape which can be manipulated and customised to simulate virtual fly over views of the monument from different perspectives for new galleries of the proposed visitor centre. The Stonehenge Hidden Landscapes Project, aims to place the site and its development through time within a landscape context using fast and accurate ground-based geophysical techniques to virtually recreate the Stonehenge monument within its surroundings as it was more than 4000 years ago. Gaffney et al [15] describe details of how the project has mapped, visualized and interpreted landscape-scale data. The data are interpreted within a data rich three-dimensional data cube that has provided new insights regarding the apparent blank areas surrounding Stonehenge. When processed, the millions of measurements will be analysed and incorporated into 2D and 3D gaming technology.

3 Data Gathering and Modelling

The digital design methods that were involved in re-imagining and re-constructing a 3D model of Stonehenge are outlined in this section. The modelling phase of the project began with a research site visit to Stonehenge in September 2009. English Heritage granted the team permission to investigate the Stone Circle to record the site for educational research. Digital photographs of each stone were shot at vertical/horizontal alignment to each stone surface to ensure accurate planes when measuring and mapping during 3D surfacing and modelling. The site was re-visited for a second day as English Heritage visitors to experience and record the site from the wider perspectives and also to evaluate the complementary audio tour hearing loop as educational heritage media. The significant areas around the Stonehenge site including the Cursus, Woodhenge and Durrington Walls were walked, experienced and recorded with video and drawings for future modelling and pre-visualisation research development work.

English Heritage's National Archives kindly donated and granted permission for the photogrammetric 3D point cloud data files to be used for 3D modelling of Stonehenge in this project. The archived data received included 91 CAD files with each individual stone separated into four separate surface files of raw point cloud data on a CD. Historical drawings and survey plans of Stonehenge were also sourced from the English Heritage Monuments Archive database. The maps and drawings have been invaluable and used to accurately locate and assess the correct position of all stones and how each stone needed to be placed where in 3D space.

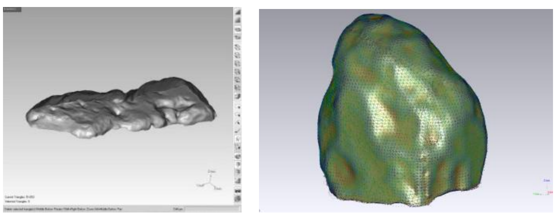

Fig. 1. Processing the point cloud data

Preparation of the sourced photogrammetric scan data required many hours of intensive sequences of careful processing of cloud data using 3D scanning software. To re-create each complete stone, four or more scanned surfaces had to be aligned and merged together into a single surface. Filling the holes, cleaning and optimising each stone's surface was carried out using 3D cloud data editing software tools as shown in Figure 1. The surface data of each individual stone is then exported to the 3D modelling software. The English Heritage archive survey plans were used in combination with Google satellite maps to accurately position each of the stones onto the correct locations.

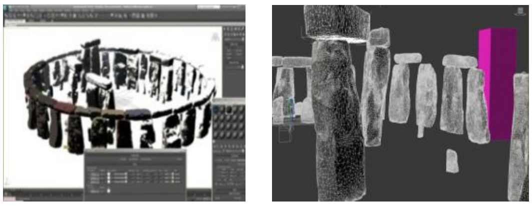

Fig. 2. Modelling phase of the stones

Figure 2 shows polygonal data of each stone being positioned in the correct location using the archive reference data. The polygon count for all the stones was optimised so that standard desktop computer hardware can easily handle the modelling and rendering processing of files. Primitive objects such as the cube shown were used as a simple method for scaling the stones to the archaeological measurements.

Measurements of the site were recorded from Google Earth in the early stages to evaluate and measure the site area where a rough model created to position the stones. Then the project team decided that accurate land data would lead to a realistic experience for the model therefore an area of land on which the stones could be positioned to generate accurately topographical 3D surfaces of the land around Stonehenge LIDAR survey data was sourced from Geomatics group.

Aerial LIDAR is an optical remote sensing technology acquired by pulsing light from a laser scanner to measure the distance between the survey aircraft and object on the ground or terrains surface. The LIDAR data is recorded from a laser scanner mounted in a survey aircraft and is used by many industries, including Energy, Rail, and the Transportation as a faster method of surveying and analysing topographical surface maps. Each 3D stone model was imported to 3D modelling software to be individually positioned and aligned on LIDAR data in 3D space. The distance of each point (vertex) in LIDAR data represents one meter therefore for accuracy other positioning methods were applied as discussed below. There were also some non-scanned and missing stones on the Stonehenge site that were not available in the data set provided. The un-scanned/ missing stones were duplicated using very similar stones. Referring to the archive data enabled the team to complete the full set of sarsen stone circles and the horseshoe of blue stones for Phase 3vi.

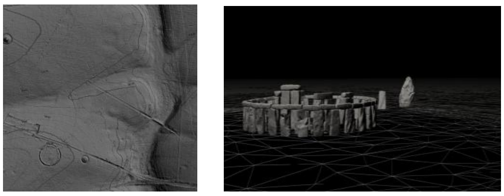

Fig. 3. LIDAR Data with Stonehenge 3D model

The researchers identified an area of one square km that included the Stonehenge site, part of the avenue, and nearby burial mounds. The stones were repositioned on a topographically accurate surface layer made using the LIDAR data. The LIDAR data supplied was in ASCII file format and contained 1000x1000 elevation points which was converted to 3D surface data as seen in Figure 3. In Figure 3 the LIDAR data is imported into 3D modelling software with polygon counts reduced. During this process the roads, paths and bridges were digitally 'cleaned' to attempt an authentic representation of the original historical iterations of the site.

4 Digital Design Techniques

To create a realistic and believable digital 3D model of Stonehenge, the use of scanned 3D digital data, LIDAR data, virtual physics systems and particles sun, wind, rain, fire and the introduction of virtual human characters was an important focus in the creation of each stage of archaeological visualisation. These experimental approaches in the project enabled augmented atmospheric, and realistic game experiences which can potentially encourage viewers to explore restricted sites both online or on site with their aesthetic senses, emotions and imagination. The application of the data in the creative design process is described in the section below and outlines digital tools and methods extensively used in the creative industries.

4.1 Product Design techniques

Laser cutting and 3D rapid prototyping are commonly utilised design tools and enhance product design approaches and techniques so were incorporated to support the recreating scaled physical virtual on the project. The research team felt it important to understand the environment and materials through touch and to spatially experience the site in real life before creating a virtual model which may lead to new heritage products in future. A 3D printed physical prototype could also offer archaeologists an experience of monuments or whole sites in the same way as for Product designers and engineers to evaluate design problems design iterations. The following design stages were used to create physical prototypes of stones:

a) Laser cutting and hatching of site maps for positioning of stones.
b) Solid modelling and analysis of stones properties.
c) Physical scaled rapid prototype of the Stonehenge model.

Figure 4 shows a Stonehenge map hatched onto MDF with a laser cutter used to locate position of individual stones and the size and shape of stones. Vector drawings were generated from the archive map and the base board for the Stonehenge model was drawn using an Epilog laser plotter cutter, which produced jigsaw cut-out pieces for the base sections.

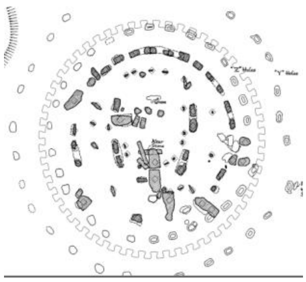

Fig. 4. Laser Cut Stone locations on MDF

To evaluate the correct position in the site of each stone, an archive map of Stonehenge was converted to a vector drawing and then sent to the laser cutter to produce an MDF board for the prototype Stonehenge model as shown in figure 4 and figure 5.

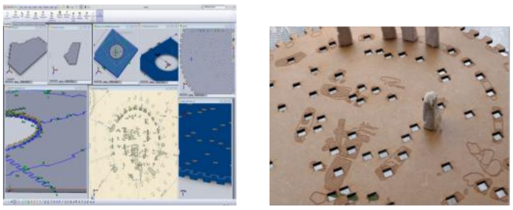

Fig. 5. Laser cutting and prototyping

The Z-Corp 3D printer was used to create powder based stones. The 3D human characters shown in figure 6 were created by printing in the Stratasys fused deposition modelling (FDM) machine. The stones were reduced in scaled proportion to a cost effective dimensions and proportions and then 3D printed.

Fig. 6. 3D prototypes, laser cutting and hatching

Using Solidworks modelling software each stone is processed and wall thickness added where individual pieces can be mass manufactured as shown in Figure 7. Solid modellers have become commonplace in product design, machine design, engineering and analysis. Design work on components is usually modelled on individual parts and created in related assemblies within the context of the whole product. The models generated using freeform and solid modelling methods are generally used in designing product for manufacturing for example injection moulding process. These models are for injection moulded parts and usually have both surfacing and sketch based features added. 3D CAD is used from conceptual design to detailed engineering model of assembly generations, 2D drawings of physical components, stress analysis, dynamic analysis, and rapid prototyping and manufacturing.

The Figure 7 shows the development of solid model from the cloud data. Further processes such as cutting and adding features were tested in this phase. The Solidworks software was used for analysis of weight, centre of gravity, volume of each stone. This phase of the project also included creation of product design elements such as manufacturing methods including injection mould, material parameters.

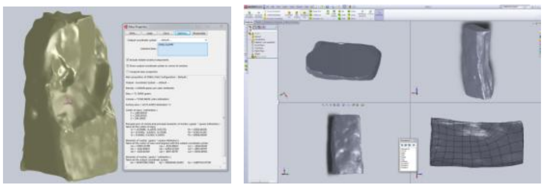

Fig. 7. Solid Modelling and analysis

Using the density of the Sand Stone, the analysis carried out in the software has resulted that the mass of the stone, volume, centre of mass were accurately calculated. The stones shown in Figure 7 has a height of 80mm with production weighted 70 grams using polystyrene material. This analysis might be useful for detailed archaeological rethinking through applied use of the 3D stones to analyse how the stones were transported, raised, lifted and positioned.

4.2 Texturing, Rendering, Animations.

Rendering is the process of generating digital visuals that can accurately represent and enhance the forms or objects created within the 3D Studio Max software. There are a number of rendering tools and methods available such as Iray, VRay, and Brazil. In this research Mental Ray rendering tools are used for creating photorealistic visuals. The Mental Ray Sun system allows the user to create a daylight and sunlight system allowing scenes with photorealistic physical lighting. Mental Ray uses ray tracing by tracing light travelling through the objects created where the rays react on hitting the object. Variable qualities depend on the type of object, or the material used. Slider tools allow the user to have greater control over the details and rendered output. The use of shadows and location of the sun are fundamental to the virtual construction and interpretation of the site. The rendered images in Figure 8 show a calculation of lighting from the sun projected on Stonehenge. Mental Ray is also used to visualise synchronous dates and times to actualise realistic environmental physical conditions in the past and future. Mental Ray simulates the precessional locations of the sun projected onto Stonehenge and results in the generation of accurate moving shadows. To evaluate human activity in the Stone Circle (Figure 8) a virtual human character was added to test scale and begin 3D character animation experiments. There are infinite numbers of options of environmental conditions that can be set according to the researcher's requirements. These can be aesthetic designer settings or archaeologically more accurate dates can be defined depending on the project. Shadows, time changes, grass textures and tree models were tested and used for realistic environmental features.

Fig. 8. Lighting, renderings, and shadows

4.3 Visual Effects

The Visual effects (VFX) are the various processes where imagery is manipulated to create environments which look authentic or naturalistic. Visual and environmental physical effects were introduced to enhance the animations and to help to represent how Stonehenge phase 3vi might have been used during a ritual ceremony. Figure 9 and 10 show 3D particle effects. Particle effects tools were tested for generating sizes and qualities of fire. Parker Pearson et al [16] suggest that fire would have been created as a heat and light source for use in cooking and ritual ceremonies in Stonehenge as large quantities of burnt and unburnt human remains from Stonehenge. 3D physics tools available in 3DStudio Max software enable fire, smoke, rain and water to be simulated and parameters modify accuracy of environmental conditions for application to enhance evaluation or visualisations.

Fig. 9. Fire and environmental effects

Fig. 10. Simulation of ritual fires

As one possible project outcome is interactive educational 3D gaming, the team focused on simulating realistic conditions of rain and wind moving around the stones and across Salisbury plain. Figure 11 shows visual programming of rain particle creation falling at Stonehenge. Particle flow system programming enables the simulation of directional rain in the form of individual drops that fall on and appear to touch the stones or floor and then a series of secondary splashes have been created to show the forces of rain.

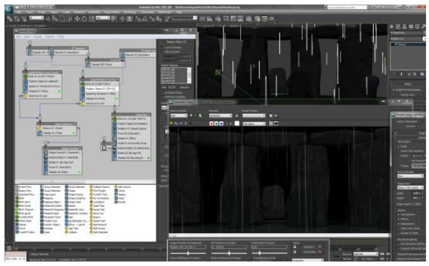

Fig. 11. Rain Particle and splashing effects

Fig. 12. Wind and Mist with Stereo visualisation

Wind, mist effects and stereoscopic renderings were also generated in 3D software as seen in Figure 12. In this part of the experiment all the stones are defined as solid objects and the 3D particle wind are set to flow through the gaps between.

5 Interactive 3D applications

In earlier stages of the acoustic experimental research work, Till [17] sourced a basic digital model of Stonehenge from Imigea digital modelling company for initial acoustic tests in Odeon room simulation software shown in Figure 13.

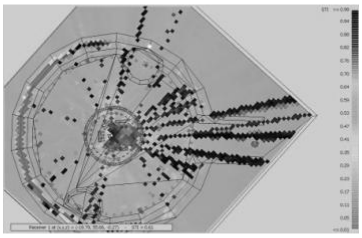

Fig. 13. Sound analysis in Odeon software.

During this current phase of the research; experiments involved stages of 3D processing of the photogrammetric scanned stone files sourced from the English Heritage Archive and modelling on a LIDAR landscape as discussed in sections 3 and 4. With the structure of the Stonehenge model completed the team felt confident that the further work being carried out was now structurally and naturalistically realistic and therefore had the potential to produce a virtual 3D model of Stonehenge for use in much more detailed acoustic experiments, virtual exhibitions and for interactive heritage learning applications.

To test the model in interactive environments, the stones were transferred to two different 3D virtual interactive environments (Unity 3D and Cry Engine) for evaluating experiential interactivity and further potential for heritage game development. In these environments the visitor can walk around 3D Stonehenge, navigate using basic keyboard, mouse or joystick interactions and can virtually experience surface materials, lighting and other environmental conditions. 3D human characters were added to the environment for testing user interaction. The Crytek game engine was used to create virtual environment for heritage gameplay as shown in Figure 10. Crytek features a vast number of tools for creating environments and character editing tools and AI programming.

Fig. 14. Stonehege 3D model in Crytek Game Engine

In the most recent and final phase of the project the team was approached by commercial multi media company Ribui ltd. to include the Stonehenge model created by the University of Huddersfield 3D research team into an interactive educational iPhone app called “The Stonehenge Experience” This app was released online to the public for WinterSolstice2011.

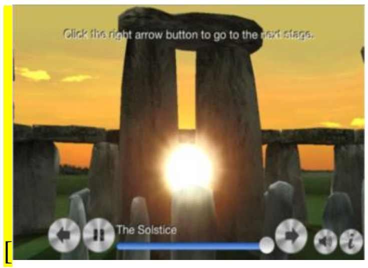

Fig. 15. Stonehenge Experience iPhone application

The screenshot in figure 15 from the Stonehenge experience app show the 3D model positioned with functionality in the completed application. Using the app visitors can virtually navigate into the centre of the Stone circle and look around, and put in earphones and hear the echoes that come off the stones. Users of the app can navigate the Stones, site and timelines interactively and choose where to explore and focus on specific areas of historically accurate information.

6 Conclusion

This research demonstrates a series of creative arts approaches and methods that can be integrated within archaeology and cultural heritage research and development for virtual applications. The collaboration has combined many different types of data and technologies. The researchers have outlined the technical methods involved in recording the data and 3D modelling the stones to re-construct Stonehenge accurately. This paper also describes how the collaborative relationships between professionals from art, design, music, and other related subjects have evolved through practice based approach by using the same data differently across different disciplines. The research has shown how visual artists and designers can contribute unique insight, experiences and skills to further improve the ways in which archaeologists bring the sites and past activities to life for contemporary audiences and public exhibition which increasingly expects a more active visually rich content.

The world is changing and expanding through immersive experience with technologies, and also advancing through interdisciplinary research being responsible for transforming the boundaries of traditional science, arts, and humanities disciplines. The pervasiveness of high quality experiential gaming will inevitably increase cultural expectations for direct engagement for interacting with emerging 3D technologies which are widely available and used for entertainment at home such as PlayStation PS3, Xbox 360 3D games. The natural evolution of this cultural phenomenon surely must encourage further support for enhancements in online exhibitions, virtual heritage experiences, and interdisciplinary research.

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