UAVS as a platform for earthwork heritage: monitoring, documentation and visualisation

Thesis Submission for Ph.D in Geography

Keele University

June 2023

Helen Malbon

Abstract

Conservation of Cultural Heritage has been a mainstay of UNESCO and other such organisations for decades, whether it is artefacts, buildings, or earthworks. With the increase of tourism, urban encroachment, climate change, or naturally occurring processes, the need to monitor and document earthwork heritage sites should be a priority. The increasing use of Unmanned Aerial Vehicles (UAVs) in wider research across disciplines has opened a cost-effective method of data collection for disciplines like geography, geology and archaeology, all subjects that use aerial imagery.

The landscape of the Peak District has a diverse history still remaining and visible that is of increasing interest to tourists. By demonstrating the use of UAV derived imagery for monuments, this investigation establishes that UAVs can provide high resolution imagery of monuments within the landscape. This is particularly useful considering the possible costs incurred and when a minimum area requirement can limit access to satellite imagery. From there, it establishes that the contemporary data can be utilised to estimate modelled topographies of heritage sites prior to construction. This topography utilises data from the contemporary site in order to rebuild the monument, which was achieved using both remnant data and measurements provided by earlier researchers. The rebuilds and contemporary sites can be used for volumetric analysis, to understand change that may have occurred over time. Organisations dedicated to the conservation, preservation and documentation of earthwork heritage can utilise the methodology in a cost-effective way to monitor as often as is needed to protect them. Finally, it is discussed how these digital heritage images and other types of visualisation can be used not only within academic research, but also to provide access to the public who cannot reach these sites, or do not feel comfortable doing so, as well as defining how the created images, both 3D and 2D, can be used to make the public aware of heritage.

Acknowledgements and Dedication

I would like to thank my parents for their unwavering support of my education, even when I did not feel like I was able to continue, or made them doubt. They have been as patient as they could, reminding me when they could not, but we got through in the end.

I would like to thank the Peak District National Park Authority, Dove Holes Community Association, English Heritage and the landowners and grazers for their permissions, kindly given, to be able to fly over these heritage sites. Also, many thanks to those at PDNPA for providing me with archaeological reports on the sites to use for background information. I would also like to thank Mrs Doreen Hails, a family friend, who kindly loaned me her short article on Arbor Low and Gib Hill when I could not find an online version.

I would like to thank my supervisory team for helping with the initial start to my work.

I would very much like to thank my supervisor, Dr Alex Nobajas, who has been my supervisor for my third year dissertation, my Masters dissertation and now, my doctoral thesis. He has ‘put up’ with me for many years, and I wholeheartedly thank him for his advice, help and reassurance that I know what I am doing.

In dedication to my parents, Carol and Stephen.

They encouraged me to get what they never could

Contents

List of Figures, Tables and Appendices

Abbreviations

.DAE – Digital Asset Exchange file

AE – Archaeologists' Estimation

AHD – Authorised Heritage Discourse

ALS – Airborne Laser Scanning

BAME – Black, Asian and Minority Ethnic

BC/BCE – Before Christ / Before Common Era

BIM – Building Information Model

CE – Common Era

CH – Cultural Heritage

CITC – Cook Inlet Tribal Council

CPRE – Council for the Preservation of Rural England

CSTT - Control Surface Transitioning Tail-Sitter

DEM/DSM/DTM – Digital Elevation Model / Digital Surface Model / Digital Terrain Model

DOI – Digital Object Identifier

DPC – Dense Point Cloud

DTTT - Differential Transitioning Tail-Sitter

EH – English Heritage

ELC – European Landscape Convention

GCP – Ground Control Point

GIS – Geographic Information System

GLAM – Galleries, Libraries, Archives and Museums

GLONASS – Globalnaya Navigazionnaya Sputnikovaya Sistema

GNSS – Global Navigation Satellite System

HCI – Human Computer Interaction

HE – Historic England

HER – Historic Environment Record

HMD – Head Mounted Display

IALE – International Association for Landscape Ecology

IBM – Image Based Modelling

ICOMOS – International Council of Monuments and Sites

IT/ICT – Information Technology / Information Computer Technology

LAAP – Low-altitude Aerial Photography

LiDAR – Light-imaging Detection and Ranging

LMA – Local Management Agreement

LRM – Local Relief Modelling

MENE – Monitoring Engagement with the Natural Environment

MPA – Maintained Property Agreement

MT – Modelled Topography

MVS – Multi-view Stereo

NGO – Non-Governmental Organisation

NIR – Near Infrared Radiation

NMP – National Mapping Programme

OD – Ordnance Datum

OE – Original Elevation

PCA – Principal Component Analysis

PDF – Portable Document Format

PDNP – Peak District National Park

PDNPA/PPJPB – Peak District National Peak Authority / Peak Park Joint Planning Board (formerly)

PSS – Phase Shift Scanners

RH – Relative Height

RMSE – Root Mean Square Error

SAR – Synthetic Aperture Radar

SDG – Sustainable Development Goals

SFV – Sky-View Factor

TLS – Terrestrial Laser Scanning

TOF – Time of Flight

UAV – Unmanned Aerial Vehicle

UN – United Nations

UNESCO – United Nations, Educations, Scientific, Cultural Organisation

VH – Virtual Heritage

VRM – Virtual Reconstruction Modelling

VT – Virtual Tourism

Chapter 1 Introduction

1.1 Brief Overview of UAVs, Aerial Imagery and GIS

Aerial imagery first started in the 19th century, with a French national named Nadar, from a tethered hot-air balloon above a village (Verhoeven, 2009) and since these formative years, assisted by both World Wars, Unmanned Aerial Vehciles (UAVs) – also known as drones – have been used in fifty militaries worldwide (Cook, 2007). In recent years, the uses of UAVs have increased for research and commercial benefits (Peterson, 2006), in research as data collection platforms across a diverse range of industries and disciplines: military, construction, geography, and archaeology to name a few (Campana, 2017; Nobajas *et al.,* 2017; Nesbit *et al.,* 2018; Campana, 2020; Mohsan *et al.,* 2022). Other earth observation techniques have been in use for several decades, such as satellite imagery (Chen *et al.,* 2017). IKONOS satellite data has been used to detect Mayan settlements (Garrison *et al.,* 2008), multispectral ASTER satellite data in result verification in older datasets such as from LANDSAT or CORONA images (Altaweel, 2005), the latter being commonly used in the 21st century (Goossens *et al.,* 2006).

The accessibility has only grown since UAVs became more affordable for recreational use and cost-effective platforms in academic research (de Reu *et al.,* 2014) over other aerial gathering platforms like helicopters and aeroplanes, because unlike both the former and satellite derived imagery have minimum area coverage required, unlike UAVs (Sozzi *et al.,* 2021). Often, they have on-board cameras which Stek (2016) and O'Driscoll (2018) have used them for site detection, and for identifying previously unknown features, even at destroyed sites. Stek (*ibid.*) concluded that using UAVs was effective and a tool for site prospection, particularly for threatened sites. With many new sensors are being made solely for UAVs (Campana, 2017; 2020), the uses are growing.

Chapter 2 shall discuss the methods and senors used in data collection and analysis of landscapes and archaeology. It shall cover LiDAR, which is a commonly used sensor by archaeologists (Challis *et al.,* 2008; Bollandsås *et al.,* 2012; Risbol and Gustavsen, 2018), but is very expensive compared to aerial imagery. However, UAV-derived aerial imagery can perform as well as LiDAR in image collection of less vegetated environments, with Root Mean Square Errors (RMSE) in the imagery, outputs and data collection being very close between LiDAR imagery and RGB cameras on-board (Salach *et al.,* 2018).

Geogrpahical Information Systems (GIS) is frequently used to display location data and descriptive data in nearly every field of industry or research (Esri, 2022). It is used in planning, public safety, education and government to name a few to create actionable maps and visualisations (Esri, *ibid.*). By using GIS tools that are more useful geographically, volume analysis and visualisations of inactive sites (i.e. not undergoing excavation) can be achieved, as (Dell'Unto and Landeschi, 2022) exaplined: regarding volumetric analysis, though it had been envisioned back in the 1990s (Reilly, 1991), Dell'Unto and Landeschi (2022) stated that there had not been many applications of volumetric data in GIS. They went on to say that it was due to a lack of pipelines to handle the format like voxels or closed vector data in georeferenced spaces, and that most GIS software has not allowed for the handling in spatial relation to other features or objects such as rasters and shapefiles, key components in GIS, thereby limiting volumetric analyses, most specifically for stratigraphic analysis where it has been more frequently applied.

In consideration of this lack of volumetric application, Ciminale *et al.,* (2009)'s investigation concluded that multidisciplinary research produced useful information of landscape and heritage within it by using GIS. Interdisciplinarity of geography and archaeology is somewhat brought together in this investigation, but it is not the first to do so; since the 20th century, geographers and archaeologists in the UK have generated distribution maps of archaeological features (Goudie, 1987), and there are more ways in which the two disciplines have come together, such as the concept of time geography, archaeology and GIS (Mlekuz, 2010).

1.2 Rationale and Location

This PhD is built upon work the author completed for a master's degree, where the focus was also of reconstruction and 3D modelling of one site (Malbon, 2017); however, this PhD was to refine the methodology to make it smoother, more functional and to test it at other sites, to properly determine if the methodology worked, and was a feasible workflow using UAVs as effective platforms for site monitoring, with new data collected and an altered methodology.

In consideration of the growing research uses of UAVs in geography, archaeology and other industries and fields, utilising a comparatively cost-effective data collection platform may be something that could be of value to Non-Governmental Organisations (NGOs) that have care of these sites, but also how else the data can be utilised. John Barnatt, a senior archaeologist for the Peak District National Park, has explained that new technologies are being combined with traditional archive methods (PDNPA, 2022) into a kind of "virtual archaeology" for the entirety of the Peak District and without touching a single bit of the landscape by combining historical documents and modern computer mapping. Considering this, and the apparent focus on documenting archaeological digs (de Reu *et al.,* 2014), focusing on earthwork heritage sites appeared appropriate, especially those that have not been excavated in decades. This was advantageous because of the non-intrusive nature of aerial image collection in order to provide information on site health without disturbing them.

The sites chosen were within the county of Derbyshire, and three inside the Peak District National Park (Figure 1.1). All four sites were selected because they are sizable earthwork heritage monuments, constructed from earth, stone, chert and rubble that have survived into the present day. Three of the four are dated to around the 3rd millennium BCE (Edmonds and Seaborne, 2001) - the henges Arbor Low and Bull Ring, and the combination long and round barrow Gib Hill - and the youngest is a motte-and-bailey castle from the 11th or 12 the century (Landon *et al.,* 2006). The Peak District was the UK's first national park, (PDNPA, 2020a) and is 1500 square kilometres (Edensor, 2017).

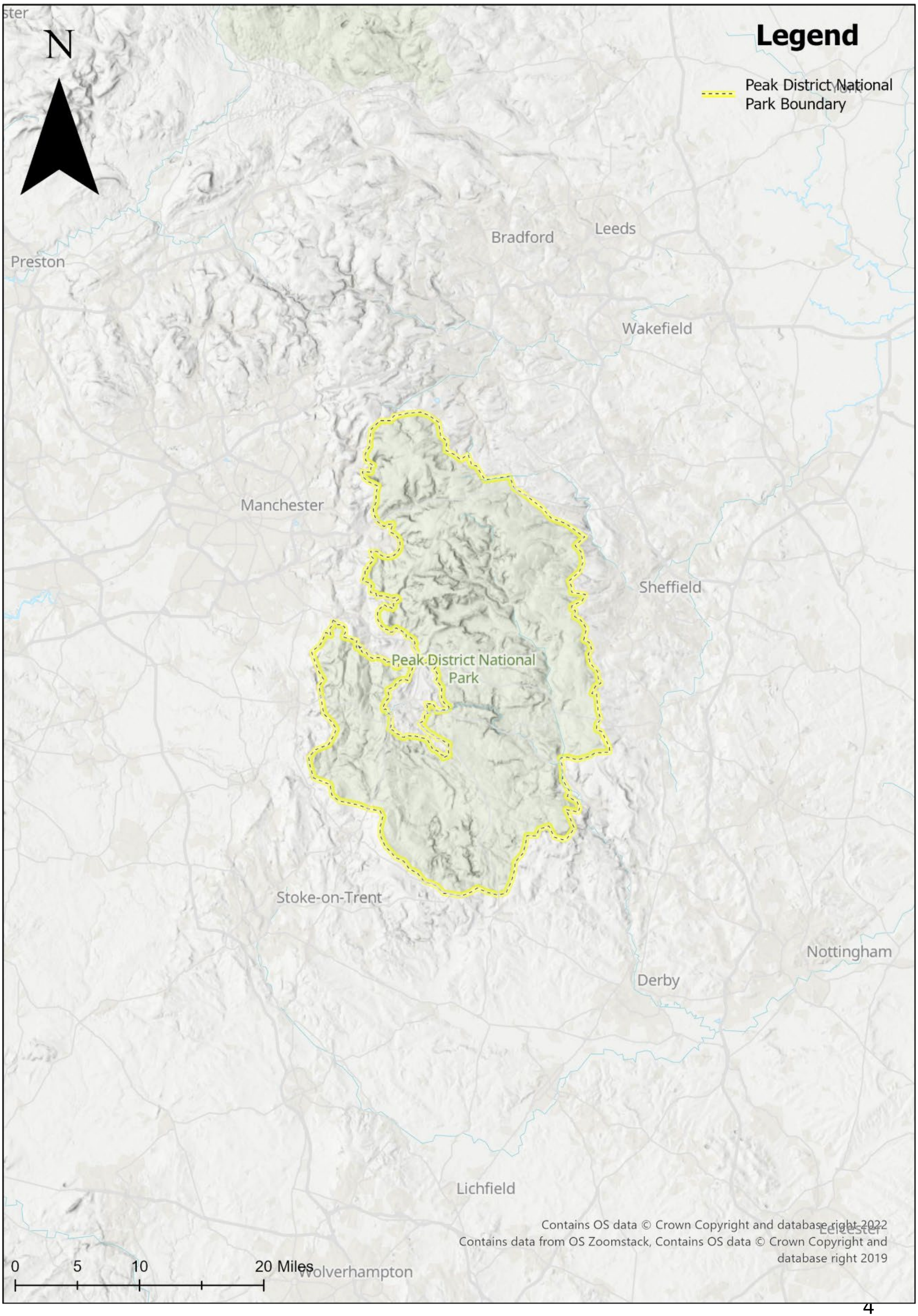


Figure 1.1: Peak District National Park (yellow line) location in central England, (Image Credit: Crown Copyright and database right, 2019, via ArcGIS Pro).

1.3 Aim and Specific Objectives

The aim of this investigation was:

- To explore combining UAV-derived aerial data and GIS-based methodology can aid in the monitoring, documentation and visualisation for earthwork heritage sites, and discuss how the outputs can have uses beyond research into improving public awareness, and access to heritage.

This would be achieved by following four objectives:

- Combine UAV aerial imagery, Structure-from-Motion, and GIS to document four earthwork heritage sites
- Explore the use of GIS to visualise contemporary damage and calculate volumetric data of each site
- Combine archaeological estimations and contemporary site data, UAV aerial data and GIS to hypothetically reconstruct the feature, and calculate the volume of the hypothesised 'original' heritage feature
- Discuss how the data could be used for further archaeological and geographical research, and to improve public awareness and access to heritage sites

1.4 Brief Methodology

In brief, the methodology started with gaining permission from landowners and organisations that own and/or care for the sites. Once achieved, flights were conducted across two days in February of 2020, around about 60 to 90 minutes for each site, size dependent. The use of a UAV was because Tahar and Ahmad (2012), Lindner *et al.,* (2015), Stek (2016), Federman *et al.,* (2018), agreed they are suitable for this type of surveying and data collection.

Once collected, the technique of Structure-from-Motion (SfM) was used with the software AgiSoft Metashape; the algorithm works by aligning images by identifying matching features across them (Westoby *et al.,* 2012; Furukawa and Hernandez, 2015; Aicardi *et al.,* 2018; Nesbit *et al.,* 2018). From there, outputs created such as Digital Elevation Models and orthomosaic images, were imported into GIS software to undergo volumetric analysis and attempted reconstruction using both data present at the site and estimations suggested by archaeologists. O'Driscoll (2018) concluded that utilising GIS software with aerial imagery was advantageous, as previously unidentified features could be observed even in destroyed sites, and the tools within like slope and aspect were very useful. Bennett *et al.,* (2012) reviewed these data visualisation techniques, alongside others such as Sky-View Factor that uses diffuse light, resulting in displaying total light amount each pixel is exposed to with a fictitious sun/light source in the hemisphere (Kokalj, *et al.,* 2011; Bennett *et al., ibid.*).

Reconstructions of the sites were attempted, some of the complete monument, one of a focused part, due to limitations present at the site and chosen in order to test the limits of the methodology. Although reconstructions of heritage have been of some debate over the last few decades, with UNESCO calling it irrational (UNESCO, 1976), and that it denied histories of sites (UNESCO-WHC, 2005). However, growing technologies and growing concerns of heritage safety make it perhaps less problematic (Khalaf, 2018), and considering the number of charters focused on heritage, only two speak on aspects of virtual heritage: the Sevilla Charter and the London Charter (Statham, 2019), though they are more concerned about authenticity and scientific rigour, therefore the methodology and research must be transparent, and the digital models must be defined as hypothetical models (London Charter, 2009; Statham, *ibid.*; Falconer *et al.,* 2020; Unger *et al.,* 2020).

1.5 Thesis Structure

This thesis consists of seven chapters overall in order to lay a foundation for, and address, the aims and objectives of this research.

1.5.1 Chapter 2

Chapter 2 is the Literature Review of theoretical considerations of heritage, why and how it matters with regard to the landscape and the value it has to people. It then goes on to explain what types of heritage are the focal point of this research: earthwork heritage monuments. The final three sections of this chapter focuses on the scientific aspect of the research, by explaining in brief the background of modelling in archaeology and how GIS is combined with landscape ecology, phenomenology and affordance in brief. Then it moves onto modelling techniques, GIS analysis and why digitisation and monitoring matters.

1.5.2 Chapter 3

Chapter 3 is dedicated to the wider location context of the Peak District by named regions, the environment in brief from prehistory to more recent times, before demonstrating where each site is in the Peak District, the histories, conditions and land uses of the sites in order to aid in the understanding of what the features are and why they were chosen for this methodology.

1.5.3 Chapter 4

Chapter 4 explains, in full, the use of UAVs, the selection of UAV for this research, how SfM works in more detail and the common procedure inside Agisoft Metashape and GIS software. Following that, site specific procedures are explained in full, concluded with the description of 3D model printing as a possible outcome and how that would happen.

1.5.4 Chapter 5

Chapter 5 is the results chapter. It is part visual imagery outputs, and data tables of the volumetric analysis. The images are either a selected oblique of the contemporary site, used to outline the areas of concern that can be identified, then hillshade and slope imagery to display with more detail, before leading on to the data tables of volume data of present and reconstructed monuments, the latter of which are also presented visually as an output of the research.

1.5.5 Chapter 6

Chapter 6 is the discussion chapter. Here, the limits and advantages of UAVs, 3D modelling and GIS are discussed, but also what the possibilities are of this type of data. Challenges of each possibility will also be discussed alongside the importance of access to heritage, both physically and for public interaction. The academic uses will be part of the discussion, and how this could be useful.

1.5.6 Chapter 7

The final chapter will conclude the thesis with brief discussion on the key findings, research directions and where it fits within current research. It will also briefly discuss where it has already been of use.

Chapter 2 Literature Review

This chapter outlines the main aspects of the background research of this investigation including:

- The theory and understanding of heritage and landscape together in research
- The types of earthwork heritage feature of interest
- The development of aerial photography over time and various sources of such imagery
- The uses of UAVs in research
- An overview of GIS in archaeology, geography and techniques used within; and
- The importance of digitising and monitoring of earthwork heritage monuments and sites in the landscape.

2.1 Introduction

Heritage sites and features of all types are part of the formation of the history of a place or people and when items are returned, they benefit the community (Mariam, 2009), so preservation of heritage should mean as much, and they are of global value since the formation of protective policies and United Nations Educational, Scientific, Cultural Organisation (UNESCO, 1972). A new era in the approach to heritage began on the 9th November 1993 (Hadzimuhamedovic and Bouchenaki, 2018) with the destruction of the symbolic bridge of *Stari Most*, known as the Bridge of Mostar, in Bosnia-Herzegovina during the Bosnian War (Grodach, 2002). The image of this historically important bridge in pieces as a result of warfare made it a universal symbol, albeit an informal one, of heritage destruction, and became a mandatory reference in discussions on reconstructing ruined heritage (Hadzimuhamedovic and Bouchenaki, 2018).

Heritage is part of a landscape, so losing the heritage can change that landscape dramatically, such as the Bamiyan Buddhas, Afghanistan: to the Bamiyan population they were part of the landscape (Han *et al.,* 2018), and the loss was severe, extending beyond the physical into the social. The Taliban blew them up very publicly, these towering statues were termed the centrepiece of Afghanistan's culture by Janowski (2015), and the remaining empty niches perhaps could be called a piece of artwork, but still there is an echo of the colossal loss. UNESCO made a declaration concerning the destruction of the Bamiyan Buddhas, and to combat the intentional destruction of a cultural heritage site, including those linked to natural sites, specified, "*States should take all appropriate measure to prevent, avoid, stop and suppress acts of intentional destruction of cultural heritage, wherever such heritage is located.*" (UNESCO, 2003).

Documentation and preservation is integral to UNESCO's World Heritage Convention, which aims to protect sites that benefit the entirety of humankind and global history (UNESCO, 1972). Archaeologists, researchers and other practitioners have developed methods to document archaeological sites, pre-, during, and post-excavation, such as hand drawn scientific plans of a site excavation or appearance prior to an excavation. Alongside these traditional methods, that are still favoured, documentation occurred with handheld cameras, but advancement in technologies, like utilising UAVs and aerial imagery during excavations, are becoming more commonplace (de Reu *et al,* 2014), and have become part of standard documentation of such ventures (Lai and Sordini, 2013), and such computer programmes that have the use of Geographical Information Systems (GIS) could be beneficial, which will be discussed further in this investigation. Already, GIS has been used for discovery and monitoring of heritage sites easier for decades, but archaeologists do not currently have software tailored for archaeology that uses GIS tools (Soler *et al.,* 2017), and data collection can often become expensive for research groups.

Though it can be expensive, there are a variety of equipment in use for prospection and investigation, including tools such as laser scanning, aerial photography and visualisation techniques such as aspect and Sky-View factor; these techniques can all be used to detect and identify features in landscapes, though with differing degrees of clarity and detection success (Bennett *et al.,* 2012). These techniques shall be discussed in more detail in *Section 2.7.2*.

Considering the cost of techniques like LiDAR and laser scanning, which shall be discussed further in *Section 2.6*, can be high or size dependent (Sozzi *et al.,* 2021), despite the accuracy, it does not detract that aerial imagery and GIS capable software could aid as easily in the analysis and protection of earthwork heritage sites (Hill, 2019; Vilbig *et al.,* 2020). Aerial imagery and GIS analysis also does not need to be for documentation solely of an excavation, but as this investigation hopes to urge understanding of, is that it can be utilised on comparatively untouched sites, such as those not excavated in decades if not longer, as they are more likely to be the ones damaged. Whilst the UNESCO convention aims to protect all sites, there are many sites in need of monitoring platforms for health and site management, not only from warfare and the aforementioned intentional destruction of heritage, but particularly earthwork sites which are susceptible to damage from tourism (Pedersen, 2002; Pinter, 2005), livestock and agricultural practices (University of Oxford, 2023), and climate change (Ravan *et al.,* 2023). Documenting, visualising and modelling could aid in the continued preservation of heritage, those that still exist and those lost, to protect them for future generations as UNESCO has declared (UNESCO, 2003).

2.2 Theoretical Considerations

2.2.1 UNESCO on Heritage and Preservation

Heritage has been a major component of United Nations Educational, Scientific and Cultural Organization (UNESCO) since 1972 when it created the UNESCO World Heritage Convention. UNESCO is dedicated to seeking peace through international cooperation in education, science and culture, built upon the shoulders of education ministers in wartime Europe (UNESCO, 2022).

The *Convention Concerning the Protection of the World Cultural and Natural Heritage* was adopted by the General Conference in Paris, 16th November 1972 at its seventeenth session (UNESCO, 1972). It noted that heritage sites were increasingly threatened by not only traditional forms of destruction, but by increasing social and economic issues that aggravated the situations further. Due to these threats, there was deterioration or disappearance of these sites that impoverished the heritage of the world, and UNESCO recognised that economically hindered countries lacked national scale resources for heritage protection (UNESCO, 1972). For humankind as a whole, UNESCO decided it was imperative that, in order to abide by its constitution of maintaining, increasing and diffusing knowledge, the irreplaceable heritage sites needed to be safeguarded in view of the magnitude of new threats by all member states in a collective effort (UNESCO, 1972).

UNESCO defined cultural heritage as monuments, groups of buildings and sites; monuments included "*architectural works, of sculpture and painting, elements or structure of archaeological nature, inscriptions, cave dwellings, and combinations of features of outstanding universal value*" (UNESCO, 1972, p. 2). Natural heritage was defined as "*features consisting of physical and biological formations or groups of such formations, which are of outstanding universal value*" (UNESCO, 1972, p. 2), geologic and physiographical formations and delineated sections of threatened animal or floral species, and natural sites of natural beauty or scientific interest (UNESCO, 1972).

Xiao *et al.,* (2018) explained that cultural heritage is of historical, social and anthropological value and is therefore considered to be an enabler of sustainable development, and was included in the United Nations' Sustainable Development Goals (SDGs), numbers 8 and 11. The seventeen goals were adopted by the United Nations in 2015, but UNESCO had already declared in 2013 that cultural heritage should be the central focus of sustainable development policies in the Hangzhou Declaration (UNESCO, 2013).

SDG 8.9 specifically was to promote sustainable tourism by creation of local jobs and promotion of culture and products of the local area (United Nations, 2015; Xiao *et al.,* 2018), which is part of Goal 8, the overall aim being to promote sustained, inclusive and sustainable economic growth, productive and full employment, and decent work for all. Therefore, if tourism was to be made sustainable, there also needed to be monitoring of the sites to ensure wellness for years to come. Cultural heritage was considered to be a wellspring for knowledge capital, creativity and innovation; new approaches should completely acknowledge the role that cultural heritage has "*as a system of values and a resource and framework to build truly sustainable development goals*" (UNESCO, 2013, p. 1).

SDG 11.4 focused on the protection and safeguarding of heritage, which for many types of feature – particularly easily damaged earthworks – was imperative if they were to continue to survive (United Nations, 2015; Xiao *et al.,* 2018). SDG 11.4 was a sub-goal of Goal 11, which focused on making cities and human settlements inclusive, safe, sustainable and resilient by 2030.

In the 2013 Hangzhou Declaration, nine points were decided upon for policy-makers and government officials to consider (UNESCO, 2013):

- Integrate culture within all development policies and programmes
- Mobilize culture and mutual understanding to foster peace and reconciliation
- Ensure cultural rights for all to promote inclusive social development
- Leverage culture for poverty reduction and inclusive economic development
- Build on culture to promote environmental sustainability
- Strengthen resilience to disasters and combat climate change through culture
- Value, safeguard and transmit culture to future generations
- Harness culture as a resource for achieving sustainable urban development and management
- Capitalize on culture to foster innovative and sustainable models of cooperation.

From this 2013 Declaration, the UN, at its 20th General Assembly of the States Parties to the World Heritage Convention, adopted a new policy on integrating sustainable development into the UNESCO processes of the World Heritage Convention and UNESCO subsequently launched the ‘Culture for Sustainable Urban Development’ programme (Xiao *et al.,* 2018).

UNESCO (2016) released a 300-page global report and a 30-page executive summary on Culture for Sustainable Urban Development. It focused on eight study areas across all continents, and concluded with recommendations derived from the findings of regional and thematic parts of the report to be utilised in guidelines to support policy-makers. It highlighted mostly urban heritage – as it did not have a set definition globally – and tailored its investigation to each study area.

Study area three, Europe, was recognised to have highly developed urban systems and heritage from its classical and medieval histories, which has resulted in a layering process as pre-existing structures are reused continually (UNESCO, 2016). Subsequently, since Europe was one of the centres that laid foundations for ‘urban heritage’ and the constant reuse of old buildings, it meant that conservation and regeneration makes the continent one of the largest ensembles of urban heritage preservation in the world (UNESCO, 2016).

Compare this to study area five, Southern Asia: though home to some of the oldest civilisations in the world, the historical architecture was under threat from rapid urbanization and impacts stemming from colonialism and post-colonialism (UNESCO, 2016). The high urban poverty had to be factored in alongside the insufficient mitigation policies in place across much of the area, to be used against both human action and natural disasters, which were commonplace in this region. These insufficient strategies were a result of the concept that urban heritage was not a high priority in the face of urbanization and the prevalent urban poverty in many of the countries in South Asia, including India, Bangladesh and Afghanistan, the latter having suffered critical damage from warfare in the last three decades.

Ultimately, there were three main themes within the report:

- People
- Environment
- Policies

Within these themes, were four subthemes, such as ‘human-centred cities’, ‘peaceful and tolerant societies’, ‘inclusive public spaces’, ‘safeguarding urban identities’, ‘sustainable local development’, and ‘enhanced rural-urban linkages’ (UNESCO, 2016). The conclusions and recommendations focused on the four subthemes within each theme; for cultural heritage in particular, a recommendation required that cities’ liveability should be enhanced and their identities safeguarded, and city regeneration and the creation of rural-urban linkages should have the safeguarding of heritage as an integral part of the urban planning (UNESCO, 2016). The UNESCO goals did focus largely on urban heritage, which did not have such a set ‘global’ definition as archaeological heritage (UNESCO, 2016). However, archaeological heritage features that are not made of stone, brick or other hardy materials are easily lost through human destruction and action, climate change and environmental threats, but also through time alone, with nothing else to inhibit the natural processes of nature, and so should also be considered for consistent aerial monitoring and volumetric analysis as part of the statutory protection sites have in the UK, such as Scheduling of Monuments as part of the National Heritage Act of 1983, amended in 2002 (Council of Europe, 2023) and globally.

Climate change has the potential to accelerate the degradation of heritage sites; for example, in the Arctic Circle at the Qajaa kitchen midden in Western Greenland under threat from rising air temperatures (Hollesen *et al.,* 2017). The site was well protected due to low ground temperatures, presence of permafrost and high ice content which kept the deposits anoxic. The result of Hollesen *et al.,* (2017)'s investigation suggested that the combined efforts of thermal and hydrological erosion, permafrost thaw and oxygen exposure has the potential to lead to severe loss of archaeological evidence before the end of this century. Climate change has a severe impact on organic archaeological deposits and as the climate is currently warming twice as fast as the global average, these deposits are often overlooked (Hollesen *et al.,* 2017). More regionally, riverine threats pose harm to heritage in the Derwent Valley Mills World Heritage Site (Howard *et al.,* 2016). Climate change does not pose only a danger to archaeology in the extreme climates such as the Qajaa kitchen midden (Hollesen *et al.,* 2017) but across many environments globally.

On the other hand, archaeological sites that originated within arid environments are threatened by their environment regardless of climate change; there is a certain element of vulnerability to them and there is also the consideration that these sites are commonly difficult to discover (Hesse, 2015). The damage from arid locations is exacerbated by climate change, further damaging heritages sites, which can be extensive, atop typical environment-related damage. Protecting these sites effectively is imperative for their continued existence against environmental threats, and other actions, for example, looting, urban sprawl or agricultural encroachment (Hesse, 2015).

Since archaeological and historical monuments are intrinsic to cultural heritage, they need to be discovered, documented and protected. Understanding heritage in the landscape is vital for conservation, as a result this is why documentation can become multidisciplinary because it can bring in facets utilised by other disciplines, such as GIS in geographical sciences, and because of this inclusion of other research themes, the results yielded could be meaningful for the preservation, monitoring and managing of heritage sites (Ciminale *et al.,* 2009). From there, the wider heritage landscape, can be preserved.

2.2.2 Landscape Theory

Landscape theory, also called landscape ecology, was developed by Carl Troll and became an interdisciplinary science as Troll envisioned it to be the combining of ecological and geographic disciplines; he defined it as the study of complex but casual relationships between communities and their environment (Troll, 1939) which were regionally expressed in patterns of distribution (Troll, 1971). From Troll, two differing theories developed in North America and Europe; the former focused on a bio-ecology-centred spatial viewpoint around question-driven studies, and the latter was focused on a society-centred holistic viewpoint with a focus on solution-driven research (Wu, 2006). Wu (*ibid.*) elaborated that there were underlying commonalities and ecologists from both sides recognised the importance of human influence on landscapes, but the main differences hinged largely on the ways that anthropogenic impacts and influences were integrated into research.

Beyond this, the dichotomy is simplified as Wu (2006) explained, and that the commonalities were of patter-process relationships, heterogeneity and scale issues, all of which were essential to natural and social sciences. These two theories were more complementary than they were contradictory (Wu, 2006). The American theory was consistent with Troll's definition, and it realised Troll's aspiration of combining geographical and structural approaches with ecological and functional ones. The European theory epitomised the pioneering work of Troll and others in the concept of landscape being a human-dominated *gestalt* system, derived from *Gestalt* theory of Max Wertheimer, who was a musician, logician and scientist, one of the aforementioned others whose pioneering work was embodied by European theory; the theory worked by seeking solutions in separating the subject knowledge (Wertheimer and Riezler, 1944); the theory was defined as:

"*there are contexts in which what is happening in the whole cannot be deduced from the characteristics of the separate pieces…what happens to a part of the whole is…determined by the laws of the inner structure of its whole,*" (Wertheimer and Riezler, 1944, pg. 84).

Essentially, something was more than the sum of its parts; for example, the viewing of a rapid series of stationary images indicated to Wertheimer that perception of the movement (whole) was completely different to perception of the individual images (parts) (Rock and Palmer, 1990).

Wu (2006) described landscape ecology as being interdisciplinary, where multiple disciplines interact closely for a common goal, and as transdisciplinary, which has both close cross-disciplinary interactions and participation from stakeholders outside academia and government agencies for a common goal. This may be interpreted hierarchically and pluralistically, the former emphasising the degrees of cross-disciplinary interaction and relativity of discipline's definition, the latter in reference to the need to involve differing disciplines and viewpoints (Wu, 2006). Consequently, landscape ecological studies have varying degrees of cross-disciplinarity equal to particular research questions and goals; moving from the interdisciplinary base to the transdisciplinary top of the framework alters the integration among disciplines, and the prominence on perspectives, both humanistic and holistic (Wu, 2006). Wu (2006; 2007) argued that Troll's conceptualisation embraced biophysical and pattern-process perspective, and the holistic and human perspectives which have expanded in 25 years since the inception of the

International Association for Landscape Ecology (IALE). Scharf (2014) suggested that because of goals in landscape ecology and the time depth available from archaeological sites, there was a plethora of data from various scales across space and time; data from archaeology can be utilised to create diachronic records of population sizes, structures, and biogeography and migration patterns. This information can be highly useful for decisive management of ecosystems and wildlife. Land use legacies from UK pollen showed that the presence of domestic grazing animals on Dartmoor resulted in more heterogeneity and spatial difference in moorland environments (Fyfe and Woodbridge, 2012; Scharf, 2014). Landscape theory has methods used in archaeology and GIS (Scheinsohn and Matteucci, 2004), and this relationship will be discussed later in this chapter.

2.2.3 Phenomenology

Phenomenology is defined by Sokolowski (2000, pg. 2) as "*the study of human experience and the ways things present themselves to us in and through such experience*". Gallagher (2012) stated that this definition reflected the traditional beginning for phenomenology, and the founder of the phenomenology movement, Husserl, would have accepted the characteristics offered by Sokolowski (2000); the implied first-person viewpoint meant the investigator studied their own experience by living it. Tilley (1994) wrote extensively about phenomenology in regard to archaeology, landscape, and in part human geography; there had been much in the way of convergence and parallels between archaeology and human geography, which before the 1960s, were both empiricist and concerned with distinctiveness.

Human geography looked at various spatial scales of regions in the world, and was treated holistically thereby resulting in a synthesis that started with discussions of geology, climates and soils, and ended with political considerations such as welfare and systems, as Tilley (1994, pg. 7) likened this to the "*geographical equivalent of the anthropological monograph in which 'everything' was brought together as a whole*". Similarly, it also described archaeology being concerned by space-time systematics, ordering artefacts and information into different cultural units within a delimited area that had a putative ethnic importance (Tilley, 1994). From there, there was some disillusionment and misunderstanding; a combination of positivism and functionalism brought about the concept of geography as spatial science and archaeology as science of the past, which Tilley (1994) did not look favourably on. In the foreword, it was suggested that the symbolics of landscape and social memory impact site choice, and that it was not suggested to create a divide between "*supposed economic rationality and a cultural or symbolic logic but rather to suggest each helps constitute the other*" and that people don't intentionally inhabit inhospitable environments but "*places they do occupy take on, through time, particular sets of meanings and connotations*" (Tilley, 1994, pg. 2).

Re-theorization of human geography and archaeology since the 1970s and 1980s saw space as an abstract dimension, an area in which human activities happened; this implication was that activity, event and space were separate, conceptually and physically, and this view decentred its meaning (Tilley, 1994). Space became nothing but a surface on which actions took place. The links between the 'new' geography and archaeology became very clear as Clarke (1972)'s *Models in Archaeology* was derived from Chorley and Haggett (1967)'s *Models in Geography*, and so on; human geography was seen to provide methodology bases for archaeology (Renfrew, 1969). Tilley (1994) offered the alternative view: space is not divorced from the action, it is instead involved in it, it is produced socially, has a centre in human agency and meaning. They take part in everyday 'praxis', the practical life of individuals and groups globally, and how that space is experienced is incredibly intersectional, depending on the age, the gender, the status and relationship the individual or group has with the world around them (Tilley, *ibid.*).

Consequently, phenomenology relies on the understanding and description of the landscape, the world by the individual and how to approach this is the crucial issue (Tilley, 1994). Tilley (*ibid.*) used concepts of phenomenology from Merleau-Ponty and Heidegger; the former suggested the kinetic activities of humans orientate apprehension of landscape and make it as human; space is existential and that is spatial as it opens to ‘outside’ (Merleau-Ponty, 1962). Heidegger (1972) suggested that a space receives essential being from locations, not from ‘space’; spaces open by ‘dwellings’ of humanity and staying with things that cannot be separated. Heidegger went on to propose a ‘topological’ model for the relationship between people and landscape as ‘thereness’ of being in the world, and cognition is given to social fact of dwelling to link place, cosmology and praxis (Heidegger, 1972; Tilley, 1994).

2.3 Heritage and Landscape Character Values

In 2000, the creation of the European Landscape Convention (ELC) marked a change in Europe that promoted an integrated view of landscape, where the cultural, visual and social qualities of a landscape are included with the ecological functions and indicators, the latter being an active area of research in landscape value, but the visual aspects had not been as thoroughly researched (Fry *et al.,* 2009). Tveit *et al.,* (2006) outlined a framework to assess visual character of a landscape that provides clear data on landscape structure, consistency between records that is readily available, and can be easily integrated with values on landscape functions. Within that study, they completed an extensive literature review on aesthetics, visual concepts and preferences in landscape. From there, terminology descriptive of visual quality was identified and recorded, and due to the broad base, many visual concepts were provided. Ultimately four levels of abstraction were determined by Tveit *et al.,* (*ibid.*):

- Concepts
- Dimensions
- Attributes
- Indicators

Tveit *et al.,* (2006) defined concepts and dimensions as abstract levels, and landscape attributes and indicators as facets of the physical landscape; the terminology was grouped according to this scheme. Concepts were an umbrella term with several dimensions, and these dimensions were determined by physical attributes in a landscape (Tveit *et al., ibid.*). From there, landscape attributes were described using visual indicators, and at that level, they could be measured, scaled and counted to compare landscapes and identify changes across time (Tveit *et al., ibid.*).

Nine key terms were identified by Tveit *et al.,* (*ibid.*) in the scheme from the literature reviewed:

- Stewardship
- Coherence
- Disturbance
- Historicity
- Visual scale
- Imageability
- Complexity
- Naturalness
- Ephemera

These concepts, each with their own dimensions, attributes and indicators, expressed how the visuals of a landscape could determine the value from an individual's perception, rather than ecological concepts only. Individuals largely see intrinsic values of nature and the right it has to exist (De Groot and van den Born, 2003), and people typically prefer to engage with rural landscapes than anthropogenic ones (Ulrich, 1993). There is an evolutionary theory of landscape preferences whereby it is assumed that similarities in response to natural scenes will outweigh differences across cultures, small groups of people or personal opinion (Daniel, 1990; Ulrich, 1993; Tveit *et al.,* 2006). However, this theory has widespread disagreement with regard to its assumption; research has found major differences in individuals and inter-group opinion on landscapes (De Groot and van den Born, 2003; van den Berg and Koole, 2006). The way an individual perceives a landscape can be determined by several factors: educational level, place of residence/living environment (Yu, 1995; Howley *et al.,* 2010), and age (Zube *et al.,* 1983). Places can also form a meaning to individuals and are crucial foundations for attachment, both being required to understand the variety of place-related behaviours in people (Stedman, 2008). 'Place identity' is the extent to which a place becomes an imperative symbolic part of a definition of 'self' (Cuba and Hummon, 1993; Trentelman, 2009). The meaning of a 'place' is distinguished from emotions (Davenport and Anderson, 2005), which are "descriptive" '*what it is*' rather than how attached an individual is (Stedman, 2008).

Hunziker *et al.,* (2007) argued that there were two major modes of landscape perception:

- Physical properties of a landscape that is linked to biological inheritance is *SPACE*
- Socio-cultural understanding in which landscape is *PLACE*

Space is a landscape that people are pre-programmed to perceive in a certain way but place is a landscape that an individual or social group comes to see in a certain way (Hedblom *et al.,* 2019). Landscape that is open – considered an indicator of value (Tveit *et al.,* 2006; Howley, 2011; Hedblom *et al.,* 2019) – is defined as SPACE because it links to the Savannah theory and prospect-refuge theory (Hunziker *et al.,* 2007). Mountainous regions were commonly linked to emotions, which is linked to well-being and is therefore PLACE (Hedblom *et al.,* 2019). Whilst openness is valued in landscapes, and heterogeneity was also valued, other indicators – both ecological and emotional – were highlighted as determining landscape value; in Swedish respondents, snow and glaciers were the 3rd favoured indicator, seclusion came 2nd, silence 4th and solitude 9th (Hedblom *et al.,* 2019).

Historicity, as summarised by Tveit *et al.,* (2006, pg. 241), is "*historical continuity and historical richness…different time layers, amount and diversity of cultural elements*". It is one of nine concepts that Tveit *et al.,* (*ibid.*) derived from an intensive literature review and considered a key visual concept that dominate aspects of the visual landscape that people enjoy. Historicity, as a concept, is defined fully as determined by two dimensions: the historical continuity and historical richness (Tveit *et al, ibid.*). The former represented the visual presence of different layers of time and subsequent ages, and the latter represented the amount, conditions and diversity of the cultural elements (Tveit *et al., ibid.*). It has well developed links between visual and ecological interests, such as drystone walls, field systems or grave mounds that were valued both visually and ecologically (Fry *et al.,* 2009).

Lowenthal (1985) proposed that the presence of historical elements “enlarge” landscapes, and this can impact preference and perception of a landscape (Sturmse, 1994; Hägerhäll, 1999). A wide variety of landscape attributes contribute to how historicity is experienced, and the English Heritage Historic Landscape Project identified three attributes for how landscape’s historicity is characterised, as outlined by Fairclough (1999):

- Historical process
- Time-depth
- Complexity/diversity

This historic landscape characterisation was described by Fairclough and Rippon (2002, p. 202) as being “*concerned with recognising the ways in which the present countryside reflects how people have exploited and changed their physical environment and adapted it through time*.” Viewers of a landscape, however, view and relate to heritage differently: for some it can be a personal connection – educational or local culture based – and for others it is held to national or official capacity with a far-reaching importance (Swensen *et al.,* 2013). In the same study, heritage was divided into tangible and intangible: tangible heritage – termed cultural heritage - was inclusive of all traces of human activity in the surroundings, though public discussion of cultural heritage was understood and referred to in light of how law is practised, and which resources are protected (Swensen *et al.,* 2013).

The intangible replaced terms like oral history and traditional culture, and referred to practices, expressions, knowledge and cultural spaces where the living heritage exists (Arrunnapapom, 2009). All heritage, however, has intangible elements, as stated by Marmion *et al.,* (2009), and tangible heritage is only understood through the intangible (Munjeri, 2004), so there is a duality in regard to the tangible as remains and intangible as meanings and emotions that were not intended, but exist. Expert knowledge typically associates with material items, and experts have power to define what should be preserved and define a country's history (Swensen *et al.,* 2013), and as outlined by Smith (2006), authorised heritage discourse (AHD) has a set of texts and practices that determine how heritage is defined and used in western society.

Heritage sites and their age has influence on a landscape, and this has an impact on preferences regarding historical landscapes, and the aspects that can be shared across ages, but it did not always follow that historicity made a landscape more attractive (Tempesta, 2010). However, this did not mean that historical sites of any kind can be left to fall into ruin, as the ELC states in Article 6 that all governments that ratifies the Convention must undertake increasing the awareness among societies, organisation and public authorities of landscape values, their roles and the changes in them (Council of Europe, Article 6, 2000). Subsequently, this includes the management of heritage sites through monitoring and documentation.

Mascari *et al.,* (2009) stated that landscapes, heritage, and culture interact in two directions: heritage landscapes and landscape's cultures. Heritage landscapes are a "bottom-up" direction, referring to the concrete and visual contexts of cultural heritage alongside products and processes associated with social, economic and knowledge that characterises a landscape's culture (Mascari *et al.,* 2009). Landscape's culture is "top-down" in direction, and referred to cognitive, conceptual and socio-economic patterns that enabled the processes in the heritage landscape, whether implicit or explicit (Mascari *et al.,* 2009). Heritage, as a result, has a significant part in the beauty and character of a landscape, therefore the documentation, preservation and monitoring of human heritage is as imperative as the saving of the ecological and biological aspects of a landscape.

Monitoring landscape change was typically done using ecological indicators and not a person's perception of the landscape (Fry *et al.,* 2009; Hansen and Loveland, 2012). This was due in large part to the fact that gathering social and natural science data comes with a high cost (Kienast *et* *al.,* 2015). Though a way to overcome the high cost and lack of temporal data on human perception of a landscape is to link physical data from current monitoring programmes to landscape properties as perceived by people; this would potentially make possible the ability to monitor changes in human perception of a landscape (Hedblom *et al.,* 2019).

2.4 Earthwork Features

Earthworks can be defined as a general term used to describe any group of hollows, ditches, banks, mounds, scoops, platforms, and other construction types that were built from earth and stone (Darvill, 2008). Therefore, earthworks range from hillforts to henges, to cairns, castles, and barrows.

Globally, there are numerous types of earthwork features constructed by humans from the ground up, or were natural landscape features that were altered and used by humans, such as Mam Tor, built on a 'hog-backed' ridge (Coombs, 1976) and Pilsbury Castle that made use of the natural headland (Landon *et al.,* 2006). Others were built from the ground up, for example, on the North American continent, there are the famous Cahokia Mounds Historic Site in Collinsville, Illinois, a large pre-Columbian settlement that flourished between 1000 and 1300 BCE, with an estimated population of 20,000 to 50,000 people (Vilbig *et al.,* 2020). The largest of the mounds – Monks Mounds - reach 30 m high, but over 120 mounds total were documented (Vilbig *et al., ibid.*). In the state of Ohio, there is the ancient earthwork geoglyph, the Serpent Mound, an iconic symbol of ancient America (Lepper *et al.,* 2018). The Serpent Mound is a 435 m long sinuous earth embankment, and was reported by Squier and Davis (1848) to have reached above 5 feet high (1.5 m).

2.4.1 Hillforts

In Europe, hillforts are amongst the largest archaeological monuments (O'Driscoll, 2017). Ralston (2006) suggested that upwards of 30,000 hillforts existed at some point in Europe; 100 have been documented in Ireland, and in an Ordnance Survey map from 1962 (*Map of Southern Britain in the Iron Age*) 1366 hillforts were recorded, excluding on the Isle of Man (*see* Dyer, 2003). The term hillfort, defined by Dyer (2003, pg. 5) "*suggests a defended structure on a hilltop*", but went on to explain that this term was not well-suited, but in that work retained the word over others such as *camp* and *oppidum* (walled town). Hillforts are numerous in Britain, primarily found in Cornwall, south-west Wales, and the Welsh Marches, with some dense distributions in the Cotswolds, Wessex and North Wales (Dyer, *ibid.*). There are few hillforts in the Peak District, but as Dyer (*ibid.*) stated, are sparse comparatively. O'Driscoll (2017) described hillforts as regional centres of power of the late prehistoric era, with placements that may have been along route-ways or natural resources. The phenomenon of enclosing hilltops was a recurring feature from the Neolithic onwards, and it flourished in Europe during the Bronze Age (O'Driscoll, 2017), particularly in the Middle Bronze Age, though Dyer (*ibid.*) stated evidence was seen around 3000 BC of fortifications that could be considered the beginnings of hillfort construction at Crickley Hill, Gloucestershire, and Carn Brea in Cornwall.

2.4.2 Ringworks, and Motte and Bailey Castles

Another type of earthwork monument are earthwork and timber castles with two main forms constructed: as ring works, or motte and bailey castles, which are a common feature across Europe, from Poland to Ireland (Aarts, 2007). 700 earthwork castles still exist in England (Historic England, 2018a), some built to take advantage of older Iron Age hillforts (Historic England, 2018a), such as at British Camp on the Herefordshire-Worcestershire border where an early medieval ringwork castle is situated inside an already 1000-year-old hillfort (Historic England, 2018a).

Ring works were simple yet substantial earthen enclosures around 20 – 50 m across and typically circular (Historic England, 2018a). They were the earliest Norman castles in the country, and because of the simplistic quality rendered them almost prehistoric in appearance, only scale and relative sharpness identified them as ring works (Historic England, 2018a).

The second form of earthen castles were the motte features, often created from soil thrown up from the external ditch or moat – though a few were created from naturally occurring knolls or prehistoric burial mounds – and may have been strengthened by the use of posts in a ring to retain the soil (Historic England, 2018a). Overall, their profiles vary from steep-sided to low and broad, likely decided by what type of timber tower or hall was to be constructed atop it (Historic England, 2018a). The third type, and often built alongside a motte are baileys. Baileys were an outer enclosure of mottes, also occasionally for ringworks, and constructed similarly to the latter: an internal bank and external ditch together, but some may have only been timber palisades (Historic England, 2018a). Though more the one bailey can be built with a motte, most motte and bailey castles had a single bailey (Historic England, 2018a).

2.4.3 Henges and Barrows

The word ‘henge’ comes from the name Stonehenge, and as Pryor (2004) explained, meant literally ‘Hanging Stones’, but this name was given far after the initial construction and use of the site, for a far different type of hanging, *“…I thought this referred to the way the great lintels seem to hang in the air, but Mike Pitts has convincingly shown that the hanging…. was of a more grisly sort.”* (Pryor, 2004, pg. 234). Pitts had theorised that the hanging was of the criminal punishment sort than lintelstones (Pitts, cited in Pryor, 2004).

Henges comprised various physical attributes of earthwork banks and ditches, timber posts and standing stones (Historic England, 2018b), and henges are common across the UK: there is Arbor Low in the Derbyshire Peak District, Avebury henge in Wiltshire, which is one of the largest Neolithic henges in the UK and in Europe (English Heritage, 2018a; English Heritage, 2018b), and the world famous Stonehenge in Wiltshire. They were built within the 3rd and early 2nd millennia BCE, comprised of timber posts or standing stones, ditches and banks (Historic England, 2018b). Archaeologists have in the past separated them as either stone or timber circles, but the distinction is hard to achieve (Historic England, *ibid.*). Though Burl (2000) documented 390 stone circle sites across England, Scotland, Ireland, Wales, Brittany, and southern France, henges and circles are almost completely insular to Britain and Ireland, and the henge-like structures in central Europe are now known to be older and unrelated (Historic England, *ibid.*).

Their origins are debated, but a small number of circular enclosures from 3000 BCE, commonly with segmented ditches had a role; the most famous first phase ditch and bank henges is Stonehenge, but there are others in Thornborough in Yorkshire, which may be older; the atypical henge A at Llandegai, North Wales; and the stone circles of Stenness and Brodgar in Orkney (Historic England, 2018b). The distribution of stone circles and henges are distinct (see *Appendix A*), reflective of material available to build them, but stone circles are concentrated in uplands of Cumbria, the Peak District, Devon and Cornwall, whereas standing stones are frequently found in the south-west of Britain with outliers in Yorkshire (Historic England, *ibid.*). On the other hand, henges, timber circles and pit circles are more generally found in river valleys and downlands of the south and the Midlands, and combination stone circle-henges are on the dividing line of the two areas in the south and the Peak District (Historic England, *ibid.*). Arbor Low is a combination henge, and in these forms of henge, the banks and ditches are later in age than, but when orthostats are involved, they are harder to determine in the chronology (Historic England, *ibid.*) (*see Appendix B*).

Barrows, or burial mounds, were once called *tumuli* on early maps, and this designation is still assigned to this day on modern OS maps (Historic England, 2018c). Material of construction varied from earth, stone, timber, turf and had platforms or ditches and deposits of pottery, animal and human bones (Historic England, *ibid.*). They were amongst the first features to be recognised by antiquarians, and very few in the UK survive in an undamaged state as a result of wide scale investigation in the 18th and 19th centuries (Historic England, *ibid.*), but far more have been lost, irrevocably damaged or flattened by 2000 years of agricultural activity. In order to understand how many may once have existed, nearly every parish in the UK has at least a surviving barrow, if not more (Historic England, *ibid.*).

They are common features, however, throughout Europe, particularly long barrows which are found in Germany, Poland, France, Denmark and southern Scandinavia (Rassmann, 2010). Most long barrows in England have been dated from the 4th millennium BCE (Bradley, 2020). They are built from earth or stone, the latter being known as cairns, and can be of various sizes and shapes that are characteristic of earthwork monuments in prehistory, circa 3800 to 1400 BCE, but there was intermittent construction up to as recently as the 9th century CE, around 1200 years ago (Historic England, *ibid*.). Long barrows are typically assigned to the earliest parts of the timescale, circa 3800 BCE (see *Appendix B*), rarely reach beyond 50 m long by 25 m wide, and can be oval or trapezoidal in shape, with differing heights and widths at each end, and invariably they may have had ditches that perhaps was were construction material came from (Historic England, *ibid.*).

Round barrows date back to 3000 BCE, also vary in size of a mere 5 to 6 metres in width up to monumental scales of 50 m across, and their main dating range is from 2000 to 1500 BCE (Historic England, *ibid.*), in the Bronze Age period (see *Appendix B*). The most common type is known as *bowl barrows* that have slopes of varying profiles, possibly with a ditch and outer bank, and these barrows can reach up to 40 m diameters and 4 m in height (Historic England, *ibid.*).

Earthwork features and monuments, due to the material of construction, are susceptible to erosion as all natural topographical features are at risk from, but they also face damage from livestock and human activity: farming, tourism, and hiking. An example of agricultural degradation is the Bull Ring in Derbyshire, described by Burl (2000) as a lost feature. Once comparable to Arbor Low in size and height, the Bull Ring is now much smaller than Arbor Low as it has been quarried in the last century (Tristram, 1915) and used as pasture land in its distant past (Barnatt and Myers, 1988).

2.5 Use of GIS in Archaeology

2.5.1 Origins of Use in Archaeology

Though the beginnings of GIS utilisation in archaeology began in the 1980s, it was not until the publication of Allen *et al.,* (1990)'s seminal book that application of GIS steadily increased (Scheinsohn and Matteucci, 2004). Green (1990a) acknowledged that GIS was being used by government agencies to integrate archaeology into planning strategies; for example, the National Park Service used slope, view, and distance tools to locate scenic views, to determine what can be seen from it and where it can be seen from, which is imperative in accounting the visual structure of landscape (Higuchi, 1988; Green, 1990a). Savage (1990) described that as GIS was becoming a more available tool, archaeologists tended to use GIS for site location investigation and resource management; Kvamme (1989) also came to the same conclusion due to the vast data, computational and cartographic needs. Marble (1990) proposed that GIS was a tool that was sorely needed because of the ability to organize and comprehend data that defined the true reality of exceedingly complex spatial environments where praxis and human behaviour occurred.

Applications initially focused on inventorying until it progressed to the study of human behaviour and causes of settlement establishment; it was rapidly taken up in North America as a result of cultural resource management needs, yet in Europe GIS programmes were slower to be engaged (Scheinsohn and Matteucci, 2004). In North America, the cultural resource and management centred on site recording and the adoption of GIS was related to the manual operations of site recordings, but turned to predictive site modelling for example research by Scheinsohn and Matteucci (2004) used GIS to predict and model archaeological sites in an area of poor archaeological visibility (Allen *et al.,* 1990; Kvamme, 1999). In Europe, the concerns focused on modelling cultural landscape structure, spatial and temporal definitions of sites (Harris and Lock, 1995), and landscape archaeology dominated European archaeology

(Scheinsohn and Matteucci, 2004). This was due to the different trends that occurred in North America and Europe in the way GIS was adopted into archaeological uses per what was required at the time (Scheinsohn and Matteucci, *ibid.*).

Clarke (1986) was perhaps seen as one of the first to bring attention to abilities of GIS due to the emphasis that was placed on GIS development as a tool for resource management to prevent developers from constructing on archaeological sites. An example being regional settlement pattern analysis in the Arroux River Valley of Burgundy, France; Madry and Crumley (1990) used GIS tools that could aid in predictive modelling of road courses that had segments missing. By using the corridor or optimum-route analysis to predict where the roads may have travelled assuming that the road-builders would choose the route that would be simplest to construct. The use of the line-of-sight tool – still often in use for archaeology today – uses elevation data to determine areas of visibility from a selected point, and in Madry and Crumley's (1990) investigation using that GIS tool, they determined roads often remained in sight of the hillforts and avoided hidden routes.

GIS is favourable because of three dimensions it works with:

- Time
- Space
- Form

These dimensions are imperative to archaeology, and it was hard for the discipline to cope with all three simultaneously due to limits in methods and theory (Green, 1990b). Cultural landscapes require overlays, to correlate and compare multidimensional maps that have different cultural and natural variables, time periods and stratigraphic representatives. Consequently, difficulties arise when trying to combine variables or when performing mathematical manipulations (Green, 1990b). GIS is spatially referenced, meaning it can interrelate spatially referenced data as overlays, easily manipulate data, analyse the maps, and create new data as new overlays. GIS is a powerful methodology for landscape archaeology, which is the understanding of archaeological artefacts, sites and complexes in the wider spatial realms of human experience (Denham, 2017), and the application of landscape theory: to model or recreate a past cultural and/or natural landscape within a problem-oriented framework (Green, 1990b); as Dalglish (2012) explains, landscape is an important centre for archaeological action, and plays a part in the determination of how it is understood, evaluated and altered or protected. Archaeology has been a participant in the conceptual development of landscape theory but it was not necessarily equal in geographical, sectoral or even topical spread (Dalglish, 2012).

2.5.2 Landscape Ecology, Phenomenology, Affordance and GIS

Landscape ecology and phenomenology are approaches in archaeology and landscape archaeology (Scheinsohn and Matteucci, 2004) and the use of GIS for this concept within archaeology has met with some disagreement in the time since the 1990s (Gillings, 2012). Green (1990b) proposed that the three-dimensional nature of GIS makes it a powerful tool for understanding the cultural landscape; landscape theorists considered there is a variety of elements that make a landscape such as viewpoint, range, direction (Higuchi, 1988), even light (Martens, 1890), and knowledge of the landscape (Green, 1990b) thereby making the concept of relative landscape lead to theoretical and methodological implications.

Landscape ecology has had methods transplanted from it into archaeological research (Scheinsohn and Matteucci, 2004) as explained prior, particularly the ‘patch-matrix-corridor’ model developed by Forman and Godron (1986); a patch is defined as a surface area that is different to its surroundings in nature or appearance, a corridor is a long strip that differs from areas on each side, and both are inserted into a matrix with highest connectivity and form the landscape from these aspects (Forman and Godron, 1986; Scheinsohn and Matteucci, 2004). Landscapes are furthered divided and connected by corridors which can be used for species’ migration routes. Scheinsohn and Matteucci (2004) used GIS in archaeological site prediction in areas of poor archaeological visibility, defined by Schiffer *et al.,* (1978) as the potential that a certain environment offers for detection of archaeological materials. From the investigation they determined it was a good predictor of site location, and that the methodology had wider application in minimising the cost of intensive field surveys; Scheinsohn and Matteucci (2004) identified that landscape archaeology has two main theoretical perspectives:

- Ecological: connected to processual approaches with attention on regional settlement patterns or land use
- Post-processual: focused on symbolic landscape perception developed largely in Europe and a historical archaeology context in North America

Llobera (1996) suggested that the environmental determinism is largely implicit and present in all applications of GIS. It was considered a consequence of data type and limits of representation and manipulation of the data, meaning it cannot be avoided, however Llobera believed that GIS can be employed to investigate practices using notions from sociology, geography, anthropology and archaeology (Llobera, 1996). This environmental determinism was possibly due to emphasis placed on environmental data as obtained from existing maps, but has no inherent deterministic properties, according to Gaffney and van Leusen (1995). Llobera (1996) highlights that this is a misapprehension found in critics of GIS and is due to confusion between the terms ‘environmental’ and ‘determinism’, and that archaeological studies that incorporate environmental data are never judged to be deterministic. Instead, Llobera considered the determinism to be produced by interpretation reflected through the use of the data.

GIS references a singular, abstract space and as discussed in the prior section, space is where praxis, place and all human activity takes place, but in GIS it is devoid of that agency and meaning (Llobera, 1996). A study area is bird’s-eye view, detached and spatial models are simplified versions of an entity, be it home or city, and this stress on spatial models is likely derived from a Western historical context where the study of a group is more prominent than the individual

(Haggett, 1971; Llobera, 1996). Then there is comparison across regions, a perspective that has influenced approaches in geography and archaeology; landscapes are viewed 'synthetically', removed from an individual's first-person (phenomenological) perspective of it (Thomas, 1993; Llobera, 1996). Haggett (1971) indicated to a confusion on the concept of landscape, one being "*the general appearance of a section of the earth's visible surface*" (*ibid*., pg. 11) or another word for 'region' which Llobera (1996) believed was a term which loses perspective, both visual and points of reference for a mobile individual; as a result distribution maps reinforce this removal of individual perspectives, consequently GIS outlooks and outcomes have a removed reality, and Llobera proposes that GIS can incorporate new avenues of landscape study.

Though Llobera (1996) acknowledged that space is an active agent and not passive situation nowhere things happen to it, yet he suggested there is a flaw is this approach: the lack of formal methodology. To Llobera, Tilley (1994) based most of their conclusions on field observations and that there was no attempt to understand whether the observations apply elsewhere in the landscape. This was a limitation that could be overcome in GIS by creating new map layers with data derived from the relationship between location and surroundings, which is where Gibson's *affordances* come into play with GIS and landscape study. Affordances are described by Gibson (1971) as "*the affordances of things are what they furnish, for good or ill, that is, what they afford the observer*" and by Ingold (1992, pg. 46): "*are properties of the real environment as directly perceived by an agent in the context of practical action*". Gibson (1986) explained that affordances can only be understood in relation to a subject, i.e. an individual, and a *niche* is a set of affordances that pertains more to how an individual or animal lives rather than where it lives; niche is just one amongst infinite number of affordances that can be offered by an environment (Gibson, 1986; Llobera, 1996). Affordances exist with *structures* that are constituted by rules and resources, typically material (Hodder, 1987). Rules are not a determinant of mechanical behaviour but is understood in relation to Bourdieu (1977)'s concept of *habitus*; these are a set of dispositions based on conditions of existence that inform a subject's practices tending to follow 'common sense' (Llobera, 1996). Affordances are integral to the habitus of a group because the nexus between structures and affordances is formed by the concepts of practice, so as individuals share structures produce similar practices, therefore share similar affordances (Llobera, 1996).

For archaeology, Llobera (1996) posits that particular affordances could be explored in GIS with a focus on material distribution based on a characteristic such as morphological or visual, from the perspective of an individual in that location; Llobera believed this was a more humanistic way to use GIS and that it could be used to define practices and understand that nature from the local surroundings. Similar processes are still used via GIS and Digital Terrain Models (DTMs) as Llobera (1996) used: the Wessex Linear ditches were associated with Late Bronze Age, built together or in stages, with emphasis on the ditches. Aspect of hills were investigated to determine if that impacted on ditch orientation using GIS routines; other characteristics were investigated and it was concluded that there was an emphasis on changes in the horizontal plane rather than the vertical, with 70% of ditch orientation are within less than 40 m; the builders may have been utilising the properties of morphological features (Llobera, 1996); hillcrests were studied as well as they are natural subdivisions of the landscape with 67 % of ditches are within 60 m or less of a hillcrest. In conclusion, Llobera was not using GIS in the same sense as this investigation, but it was being used for archaeology in a more humanistic method to show the potential of using heuristic GIS to explore a landscape and its processes, with improvements expected as technology advanced.

Llobera's use of GIS was admittedly experimental, and others did not wholly agree with his work; Webster (1999) felt Llobera did not fully appreciate the implication of the concept of affordance, though did acknowledge the methodological tool GIS provides because of the display capabilities and quantitative analysis systems for spatial investigation, which Kvamme (1993) also noted. Whilst Webster (1999) did not deny that GIS could be used in construction of detailed and dynamic described location to determine an affordance, but merely believed that due to perception being an inherently individualistic action – impacted by age, height, physical strength – perception could not be used with a standardized height as it was in Llobera (1996)'s investigation. Llobera (2001) acknowledged these points as completely valid, and required models of the environment and the individual, which had not been expounded upon at that time; what is sought by Llobera (2001) is to integrate affordance as an analytical element in a social framework, more so than being exact for every permutation e.g. height difference.

Llobera (2001) was in response to Webster (1999)'s article, and to explain further used GIS to aid in building past landscape perception through understanding topographic prominence; in that study, Llobera (2001) called topographic prominence a 'landscape affordance' and topographic prominence may have been an element in the socialization process and therefore making it an 'affordance' (Llobera, 1996), which is understood to be the process when an individual becomes an integral part of the society or social group. Prominence, as described by Llobera (2001), was 'felt at a location' provided a way of addressing hierarchy, rank and importance in a landscape – implying there is a symbolic reasoning related to control (Higuchi, 1988) and used as landmarks to hold space about them (Lynch, 1960). In Llobera (2001)'s work, it is called a function of height difference between an individual and their surroundings as seen from their point of view, or more precisely locations that are below their position, inside a certain radius. The definition is a relative one, but this was done purposefully by Llobera (2001).

Since the advent of GIS, understanding visual relationships between cultural monuments and the viewer has been made easier, like explained above by Llobera (2001), and aids in the predictive modelling of unknown sites (Fry *et al.,* 2004), which is beneficial for heritage management moving from object centred to landscape perspectives (Gaukstad, 1993; 2000). Fry *et al.,* (2004) compared two approaches, first being landscape archaeological analysis, and the second being GIS-based viewshed analysis. Fry *et al.,* (2004) acknowledged there was not much comparison made between different approaches at the time of publication, and did so with these two visual methods – one being gathered fieldwork, the other being computer based GIS.

GIS and the viewshed analysis tool can do several things that are harder to do from the human based analysis:

- Remove vegetation to focus on topography and boundaries of landscape units
- Distance – landscape boundaries are accurate
- Immediate digital map for comparison
- Easier modification

The viewshed analysis does have limits, it can be suspect to slight undulations in terrain that break sight lines, and have to be programmed to give more priority to closer objects, and they respond mostly to vegetation and terrain, potentially missing landscape elements that impact cognition of the view (Fry *et al.,* 2004). This use of viewshed analysis has been commonplace in archaeology and the visual relationship between landscape and cultural monument has been an active field of research for a few decades (Renfrew *et al.*, 1979; Tilley, 1994; Gansum *et al.,* 1997), and subsequently the tools such as cost path analysis have also been used in landscape research (Gaffney *et al.,* 1996).

GIS became central in analysing surface survey data by the later 1990s, it has clear function in physical landscape analysis, which recommended the application to regional surveys; in description and contextualisation of survey data, GIS is a useful tool for archaeologists (Witcher, 1999). Space and landscape challenges clear defining, but archaeologists started to embrace the idea of landscape being socially constructed, and subjectively experienced (Bender, 1993), and integral to these approaches is the de-quantification of space, meaning landscapes become social and qualitative (Witcher, 1999). GIS, however, is based upon cartography, which conveys a specific notion of space – mathematical and scientific – that reduces emotions and experience of a viewer into pseudo-scientific realities; but GIS creates different versions of the world per the creator of the map (Witcher, 1999), and the graphics available can give it an air of authority (Miller and Richards, 1995).

A point of contention in use of GIS is environmental determinism. Scheinsohn and Matteucci (2004) admit there could be some environmental determinism in their investigation; however, they agree with Gaffney and van Leusen (1995) and that by applying a model that uses spatial elements it should be doable to eliminate environmental patterning and leave the cultural factors that may have influenced the dataset (Gaffney and van Leusen, 1995; Scheinsohn and Matteucci, 2004). Environmental determinism is seen elsewhere (Llobera, 1996) which is a concern for those utilising it (Wheatley, 1996; Witcher, 1999). Gaffney and van Leusen (1995) suggested this determinism came about because of the emphasis placed on environmental data, but Llobera (1996) refuted this claim as that information has no inherently deterministic properties; archaeological studies that use environmental data are not considered deterministic, which is considered to come from interpretation through the use of the data.

Llobera (1996) did believe that GIS could be used to look at human practices by a new approach from other disciplines like geography, sociology and archaeology. According to Llobera (1996) the determinism in GIS is subtle, which were derived from geography and adopted into archaeology (Clarke, 1972). Spatial models are traditionally used, with ‘fixed’ origins overlaid and therefore are detached from an individual, meaning spatial models are simplified versions of distributions at differing scales, like city, household, scatter (Llobera, 1996); the comparison of larger systems and groups has influence many approaches in both archaeology and geography to view landscapes synthetically, thus removed from how an individual would view it (Llobera, 1996).

There is a divide between those who advocate the use of GIS and those for theoretical development of experiential types of engagement with past material and landscapes, for example, landscape phenomenology (Gillings, 2012). There is a question of whether dialogue should even be established between the two sides, and Gillings (2012) suggested that researchers who utilise GIS should explore their own unique theoretical frameworks, and also acknowledged that cautions have been against GIS users since its inception around a period of re-theorising what 'landscape' is – towards something socially constructed – though some GIS researchers attempted to engage with those developments, others did not and focused on putting into practice previously time-consuming quantitative spatial approaches, and finesse them (Hunt, 1992; Ullah, 2011). There was also the issue of the 'toolbox problem' outlined by Gillings (2012) as referring to a tendency amongst early users of GIS research in archaeology to focus on methodological possibilities that amounted to nothing more than a set of methods searching for a problem, and the technological determinism meant that nuances of the problem were subsequently compromised to fit the need of the tool; archaeologists using GIS were relegated to being a "technician".

Gillings maintained that this gap between the user and naysayers originated from Tilley (1994)'s 'dogmatic rhetoric', despite the fact landscape phenomenology has not remained static and the foundations have often been critiqued on its theoretical underpinnings and methodological integrity (Gillings, 2012). Users today need to be attuned to what they are attempting to link to as they do not need to be developing styles that originate from landscape phenomenology of 1994 (Gillings, 2012).

Other limitations of GIS were discussed in the 1990s. Many of the implementation techniques used early on were derived from geography and later adopted by archaeology, such as Clarke (1972)'s work. Witcher (1999) believed the motivation behind using GIS in archaeology was its novelty and gloss, pushed forward by new technology despite not having clarified research problems, and utilisation of the most obvious GIS functions. Without a development of a body of theory to provide a theoretical agenda, GIS tended to promote interpretations focused on economic rationality and environmental determinism, which has been a concern (Wheatley, 1996; Witcher, 1999), by becoming prone to using deterministic approaches to archaeological explanation (Gaffney and van Leusen, 1995). Zubrow (1990) described GIS software as being inhospitable and ever-changing which can be intimidating to those who are not so technically savvy, and that at the time of the publication, the GIS of the 1990s perhaps was not providing everything desired, or potentially never could. Allen *et al.,* (1990) defined that the most pressing pitfall would be the inclination to allow a powerful methodology to drive the research and practices of archaeology.

2.6 Imagery Collection Techniques

This section outlines the various sources of imagery data collection that can be used within GIS capable software and to highlight the limitations that can be a part of these methods, which may possibly impact which method, if any, are used by research groups in archaeology, geography and other related disciplines.

2.6.1 Satellite Imagery, Synthetic Aperture Radar (SAR) and LiDAR in Archaeology

Satellite imagery has been used by archaeology for the last two decades (Chen *et al.,* 2017), alongside other earth observation technologies. It has been used in studies for ancient Mayan settlement detection (Garrison *et al.,* 2008) which concluded that IKONOS satellite imagery is highly effective in site detection. Satellite data has been of use in identifying medium-scale rural patterns (Montufo, 1997), and Multispectral ASTER satellite imagery has been incredibly beneficial in verifying results found in other datasets and for location determination that cannot be distinguished in them, such as from older Landsat or CORONA imagery (Altaweel, 2005). CORONA series satellite imagery was of common use in archaeology in the early 2000s (Goossens *et al.,* 2006); it worked through stereoscopic view, taking two images of the same spot, and was used in the creation of maps in remote areas. CORONA was an espionage satellite operational in the 60s and 70s that delivered images with a resolution of 6 to 40 feet (Goossens *et al.,* 2006). It covered an area of 600-750 m sq. nautical miles in 860,000 photographs, and these images were finally declassified on 24th February 1995 (Dashora *et al.,* 2007). Since then, CORONA has been used in many archaeological studies: in northern Mesopotamia and the study of ancient road networks (Ur, 2003); in Digital Surface Model (DSM) generation for analyses of in environmental science (Altmaier and Kany, 2002); and in estimating long-term land use and land cover in an agricultural basin (Gurjar and Tare, 2019), to name some example of CORONA satellite usage. Fowler (2002) concluded that the use of satellite imagery was not a substitute for aerial imagery, but could be a supplementary tool for archaeological prospection; large features could be detected on low resolution satellite imagery and was best used in conjunction with modelling techniques; medium resolution images, such as declassified KH-4B CORONA imagery, could aid in prospection of general shapes in location (Fowler, 2002).

Satellite imagery can be exceedingly expensive to purchase and the price is determined by the intent of the research; for high-resolution images from platforms such as WorldView – a commercial observation satellite (Satellite Imaging Corporation, 2017) – in Panchromatic colour would cost upwards of \$14 per m², from Pleiades 1A/1B \$12.50, and from the QuickBird (60 cm) satellite the price went up to \$17.50 (Land-Info, 2018). The minimum order for archive imagery is 25 square km with a minimum 2 km width (Land-Info, 2018). For DEMs, the price can reach \$60, and for DEMs in Elevation 1 Tri-Stereo, \$138 (Land-Info, 2018). Archive imagery from WorldView per km² in Panchromatic LANDSAT is a satellite controlled by NASA that has free satellite data available (Landsat, 2019), removing the costs of purchasing.

Synthetic Aperture Radar works by using the forward motion of the radar when attached to an aircraft (European Space Agency (ESA), 2018), and works by producing a two-dimensional image. One dimension uses a known range, which is measured by time from transmission of a pulse to receiving the echo from the target, and a measured line-of-sight distance from radar to the target (Sandia LLC, 2018). The high resolution is determined much like other radars, by the width of the transmitted pulse; the narrower it is, the finer the resolution (Sandia LLC, 2018). The second dimension is the azimuth or along track, and is perpendicular to range; SAR provides very high resolution azimuth by using an antenna to focus transmitted and received energy into a sharp beam, which defines the resolution. However, the antennas are incredibly long – several hundred metres - and cannot be carried, therefore airborne radar collects data by flying the length of the antenna, and process data as if it originated from an antenna: this distance is called the synthetic aperture (Sandia LLC, 2018). Though the technologies of satellites are becoming increasingly available, it can become expensive, as it has been in the past (Chen *et al.,* 2017), as resolution depends on the intent of the research project, and this affects price. Chen *et al.,* (*ibid.*) commented that archaeology has benefited from SAR in the last two decades, due in large to the amount of available data, ranging from free of cost sources as from Sentinel-1, to high-resolution data from TerraSAR/TanDEM-X satellites and others. This new accessibility meant that there was renewed interest in SAR in archaeology, and this has led to prompt virtual surveys of large areas for detection and mapping of huge archaeological sites (Chen *et al., ibid.*). SAR-derived Digital Elevation Models (DEMs) at landscape scale are very detailed, as explained by (Erasmi *et al.,* 2014), but in that same investigation, small scale delineation of features was limited from InSAR data at 2 m, though it did identify several larger linear structures of the site on the Cilician Plain in Turkey, such as ancient city walls in the hillshade image.

Laser scanning is any technology that measures, accurately and repeatedly, the distance based on precise measurements of time, aggregates these measurements into a collection of coordinates, and stores them as a point cloud that imparts information on the morphology of the object or landscape that was scanned (Opitz, 2013). There are two ways in which laser scanning is used: airborne laser scanning (ALS) and terrestrial laser scanning (TLS). Resolution of the ALS imagery depends on altitude, speed, pulse repetition, scan frequency and angle; these aspects are decided by the overall purpose of the research and the subsequent commission of ALS data acquisition reflect this (Bollandsås *et al.,* 2012; Opitz, 2013). There are two types of scanner: Time-Of-Flight (TOF) and Phase Shift Scanners (PSS). TOF measure the time it takes for an emitted pulse to travel and return to the object of interest; this type of scanner was used by Bollandsås *et al.,* (2012), and Risbol and Gustavsen (2018); they used ALS with a sensor that measures elapsed time between emissions of laser pulses and the backscatter (or echo) from an object that they hit on the ground (Bollandsås *et al.,* 2012). The imagery gathered was georeferenced using the Global Navigation Satellite Systems (GNSS) in order to position the UAV/plane when the pulse was emitted (Bollandsås *et al.,* 2012). Phase Shift Scanners produce a continuous laser pulse, and is was calculated by measuring the phase shift between the emitted and received laser beams; these scanners are sometimes used in terrestrial laser scanning (Opitz, 2013). The purpose of the data defined the resolution, so lower point densities resulted in lower resolution DTMs, and high point densities resulted in high resolution DTMs (Opitz, 2013); in laser scanning technology, vertical accuracies for DTMs using ground echoes were 20-30 cm (Bollandsås *et al.,* 2012).

For archaeology, laser scanning has been a recognised technique since the start of the 21st century, but gained more usage from the latter half of the decade (Challis *et al.,* 2008), and the discipline has been benefitting from both ALS and TLS for site prospection, documentation of known sites, ongoing assessment of resources and degradation, and the overall management of heritage (Wood and Pluckhahn, 2018). A comparison has been made between the use of LiDAR and aerial photogrammetry because accuracy is highly essential in DEM/DTM generation and modelling (Salach *et al.,* 2018). However, detection success for LiDAR-derived DTMs depends on Dense Point Cloud (DPC) density; in Bollandsås *et al.,* (2012)'s investigation into this aspect, an increase from 1 point per square metre (p m) to 5 p m^2 showed significant improvement in detection success, and only some less pronounced improvements from 5 p m² to 10 p m². Salach *et al.,* (2018)'s investigation on the accuracy of LiDAR derived point clouds compared the visual accuracy between UAV photogrammetry and LiDAR. An ultralight laser scanner that can produce dense point clouds with 180 points per square metre was compared to an RGB digital camera that collects high resolution imagery, with a ground sampling of two metres; the RGB camera showed a clear increase in error of terrain when more vegetation was present (Salach *et al.,* 2018).

Vegetation such as woodlands has been problematic in the past and so many archaeological finds are unrecorded in these types of landscapes (Crow *et al.,* 2007). Computer algorithms are used to distinguish between ground echoes and vegetation echoes in LiDAR, which is required in vegetated areas, particularly in dense vegetation, which prevents such methods as aerial imagery from gathering useful data of archaeology beneath canopy or plant cover (Bollandsås *et al.,* 2012). In uncovered and low vegetated areas, the RGB camera and LiDAR scanner produced the same results with similar accuracies: the Root Mean Square Error (RMSE) for LiDAR was 0.11 metres, for the RGB camera the RMSE was 0.14 metres (Salach *et al.,* 2018). In medium vegetation coverage - plants over 60 cm - results began to alter in accuracy, with LiDAR RMSE equalling 0.11 metres, but the RGB camera result was 0.356 metres; the presence of taller vegetation was having an impact on the accuracy of the photogrammetry with a decrease in accuracy of 0.10 metres for every 20cm of vegetation growth (Salach *et al.,* 2018). LiDAR does not have the same issue, and so can be used in wooded or heavily vegetated areas (Risbol and Gustavsen, 2018) The only potential to minimise this impact on RGB cameras is to have high overlap of the images, at around 70 % to 80 %, but it does not remove it (Salach *et al.,* 2018).

Vegetation has a negative impact on Dense Point Clouds (DPCs) that are derived from aerial imagery alone, which decreases the vertical accuracy (Simpson *et al.,* 2017), therefore LiDAR can be a better technique to use in high vegetated areas only, otherwise the results from low vegetation to uncovered areas are the same for both pieces of technology, aerial and LiDAR derived (Salach *et al.,* 2018), but dense vegetation does reduce laser penetration to the ground (Bollandsås *et al.,* 2012; Risbol and Gustavsen, 2018), therefore heavily wooded areas have, comparatively, lacked in detection of cultural remains; in places like Norway, there are reams of cultural ruins that have yet to be detected beneath the woodland canopies (Bollandsås *et al.,* 2012). However, as dense vegetation does affect the ALS pulse penetration to the ground, it results in a reduced quality DTM. Therefore, a prior knowledge of the study area is required in order to select the correct LiDAR resolution and generate a high quality DTM, particularly the archaeology needs to be above ground rather than sub-surface structures (Bollandsås *et al.,* 2012). Currently archaeologists use a resolution of 1 to 5 p m $-^2$, and English Heritage suggests a resolution of 2 to 5 p m $-^2$ for wooded areas (Bollandsås *et al.,* 2012).

Whilst it has been established that LiDAR in vegetated areas outperforms aerial and satellite imagery, it did not always provide full coverage of information. Aerial imagery works as effectively in low vegetated and uncovered areas when used with high overlap, and LiDAR only detects features at ground level no matter how slight. Cropmarks and soilmarks are easily identifiable from aerial imagery, but are not detected by ALS (Challis *et al.,* 2008). This became apparent in a case study focused on the River Dove, in the Midlands, stretching 25 km from Rocester to the confluence with the River Trent at Newton Solney, equalling about 10,703 hectares; there were many features recorded in the Historic Environment Record (HER) of the area, earthwork ridge and furrow farming, earthworks relating to meadows, deer parks, a moat and miscellaneous medieval and post-medieval features (Challis *et al.,* 2008); all were identified from aerial imagery. However, Challis *et al.,* (2011a) went on to determine that LiDAR intensity data can greatly aid in interpreting airborne LiDAR data, but detection in Near Infradred Radiation (NIR) deprends on the same physical variations in corp colour that is seen in aerial imagery.

The aerial photographs used in Challis *et al.,* (2008)'s research, dated from the 1940s and 1970s, were used in order to identify nonappearance of sites on the LiDAR data, likely due to destruction over time. Challis *et al.,* (2008)'s investigation found 915 features in the 1471 hectares (13.7 %) of the study area, of which ridge and furrow farming earthworks were the most frequent feature defined. Of these sites, 84.4 % had not been defined before in the HER for the area, reflecting that there was a tendency to ignore large scale landscape features such as field systems. Some non-agricultural features were also defined that had been excluded by the HER, including an 80 x 80 metre enclosure or platform (Challis *et al.,* 2008). However, there were features in the HER that had not been detected by the LiDAR, these typically being cropmarks, soilmarks, artefacts and documentary records, and standing buildings. 76 earthworks were documented by the HER and not the LiDAR, therefore suggesting they may have been destroyed over time (Challis *et al.,* 2008). LiDAR, as beneficial as it is in vegetated areas (Salach *et al.,* 2018), produces similar results to aerial photogrammetry in low vegetation areas and does miss key identifiers of buried heritage.

Terrestrial LiDAR works similarly to ALS, except the mapping takes place on the ground, and it used for smaller geographical areas of inspection (Wood and Pluckhahn, 2018). As a result, it creates datasets with much higher resolutions than ALS does. This is due to the amount of data that is collected at one site rather than across a larger geographical area covered by ALS; it reveals microtopography that ALS does not and can map ravines, caves and other restricted spaces ALS cannot reach or work in effectively (Weber and Powis, 2014; Wood and Pluckhahn, 2018). Terrestrial laser scanning instruments need to be placed in different locations to gather the data from different viewpoints (Remondino, 2011) and an alignment of the data info a specialised reference system is required to produce a single point cloud of what is being surveyed.

Both TLS and ALS is used in conjunction with close range photogrammetry for 3D documentation, such as Lerma *et al.,* (2010)'s study; they utilised both TLS and close range photogrammetry for documentation of a cave dated to the Upper Palaeolithic era (40,000 years ago). They concluded that this integrated methodology had further potential in providing detailed DEMs/DTMs are photo-realistic products, which would improve understanding of complex cave systems, and of relief panels with minute engravings (Lerma *et al.,* 2010).

2.6.2 Aerial Imagery and Photogrammetry

Aerial imaging first began in the mid-19th century with Nadar, a French national, also named Gaspard-Felix Tournachon, who captured an aerial image of the small French village of Petit Bicetre in 1858 from a tethered hot-air balloon 80 metres high (Verhoeven, 2009). However, it truly advanced from the start of the 20th century, assisted by both world wars – though research did halt during wartime – because images initially gathered for military uses were transformed into being used for heritage documentation imagery (Crawford, 1954; Ceraudo, 2013). Whilst the world wars would simultaneously halt and advance the use of aerial imagery, the first major accomplishment in aerial surveying was achieved by Crawford and Keiller (1928) and their '*Wessex from the Air*'.

Italy and the United Kingdom, by the late 20th century, were the forerunners of using remote sensing within archaeology, which is explainable due to the long histories of both countries and large archives of aerial imagery gathered during and following WWII (Agapiou and Lysandrou, 2015). By 2007, countries such as Germany, Netherlands, France and especially the United Kingdom were producing studies on combining geophysical surveys, satellite and aerial imagery with archaeological prospection (Agapiou and Lysandrou, 2015) and as result these countries alongside Belgium and Italy are considered leaders in remote sensing archaeology by the middle of the 2000s.

In the century since its formation, aerial photogrammetry has been integrated into many surveys for heritage, such as the National Mapping Programme (NMP) run by Historic England, formerly part of English Heritage (Bewley, 2003). There were several projects that extended all over England, operating over two decades from 1992 to the 2000s (Bewley, 2003; Archaeological Data Service, 2018). The aim of the NMP was "*to enhance our understanding about past human settlement, by providing primary information and syntheses for all archaeological sites and landscapes (visible on aerial photographs) from the Neolithic period to the twentieth century*" (Bewley, 2001 p. 78; Bewley 2003, p. 278). In the 1980s, there was a debate over evidence gleaned from aerial imagery in regard to how to describe features (Bewley, 2003). Since the 1960s, it has been recognised that aerial reconnaissance is essential in archaeological investigation due to what features can be identified only from the air, such as cropmarks (Bewley, 2003). In 2002-2003, English Heritage dedicated part of its annual programme of reconnaissance to the monitoring role that aerial reconnaissance plays (Bewley, 2003). The largest part of site monitoring is done by field visitation from trained staff called Field Monument Wardens; this is because damage can be negligible year by year (Bewley, 2003).

As of 2003, 22 projects of the NMP had been completed or were ongoing, meaning 30 % of England had been mapped to the NMP standards (Bewley, 2003). These standards include mapping at a 1:10,000 scale, and a systematic and consistent recording of site description in order to easily undergo analysis of the records and repeatability (Bewley, 2003). The repeatability allowed for the sites to be studied in a landscape context and not as individual sites (Bewley, 2003). The sites are not only classified by monument type, date and form but included location, shape and size because it was assumed that sites of a similar size and shape may have a similar date and/or a similar function (Bewley, 2003), such as henge, barrow, camp or fort. The aim of this categorisation was to understand groups of classes in a landscape context, to determine distribution, and association (Bewley, 2003). From 2011 to 2014, Historic England (2018d) added 14,000 previously unknown sites to the NMP, using the same NMP standards.

Agapiou and Lysandrou (2015) noticed that there was a large discrepancy between Western and Eastern Europe, with fewer studies coming from the latter region of Europe though there is plenty of history to be had there as well. Agapiou and Lysandrou (2015) recognised that there were gaps in the transfer of knowledge and that there need to be improvements to current scientific methods and practices. Terrestrial photogrammetry, for example, has been used by archaeologists since the early 1980s, but the expense of the hardware and processing equipment meant the techniques were not commonly viable for most projects (Fussell, 1982; O'Driscoll, 2018) and that alternatives were required.

Photogrammetry is, as Fussell (1982) described it, the technique of measuring from photographs, from which a three-dimensional model can be constructed and accurately measured; a good quantity of information can be gleaned from viewing a subject in three dimensions. Photogrammetry is not always aerial, and has been collected using cameras attached to poles and kites from fixed points on the ground (O'Driscoll, 2018). However, these are not always as effective because they are potentially time consuming to set up (Born and Valli, 2012), and do not cover a whole site as effectively. Geographical positioning had a great impact on what sites could and could not be detected and documented; though aerial photogrammetry excels in low vegetation areas, it does not always produce good enough Digital Terrain Models (DTMs) or Digital Elevation Models (DEMs) in highly vegetated or forested areas, leaving a gap in the research and in the discovery of sites (Bollandsås *et al.,* 2012). Therefore, other sensors are utilised such as LiDAR; the price rises when used with an aeroplane or helicopter, which is already costly, hence, the use of Unmanned Aerial Vehicles (UAVs) is becoming more popular, as discussed in *§ 2.6.1.*

2.6.3 Unmanned Aerial Vehicles for Documentation and Preservation

Ciminale *et al.,* (2009)'s investigation resulted in the idea that multidisciplinary research yields highly useful information of a heritage and its landscape through documenting sites via

Geographical Information Systems (GIS) alongside types of aerial imagery, from aerial photogrammetry to LiDAR imagery (Bennett *et al.,* 2012), gathered from Unmanned Aerial Vehicles (UAVs). Since the early 20th century and the foundation of aerial imagery, UAVs have become a proven technology in image acquisition in the last decade, working at distances ranging from 4 metres to as high as 400 feet as per UK regulations (Drone Safe, 2018), subsequently supporting the concept that UAVs can be used as a documentation or monitoring system on archaeological sites or sites of heritage (Rinaudo *et al.,* 2012), which studies in the last decade have presented (de Reu *et al.,* 2014; Meyer *et al.,* 2015; Ilci *et al.,* 2019; Themistocleous, 2020). Low-level platforms for monitoring have been small balloons and kites, but as UAV technology has advanced and the market has experienced an expansion in the platform, there has been a large increase in sensors being created solely for use on UAVs (Campana, 2017). There are many studies into using UAVs as documentation tools, for surveys of monuments and heritage buildings, landscape and archaeological surveys, exploratory surveys, surveys of woodland areas (Bennett *et al.,* 2012; Lai and Sordini, 2013; Campana, 2017), and for arable farming (Sozzi *et al.,* 2021). Sozzi *et al.,* (*ibid.*) went on to say that UAVs were the highest price per hectare at 43.4€, but they did not require a minimum area like satellites did, UAV derived imagery was better suited to high spatial and spectral resolution, and this would make them profitable when used for these high value applications.

Unmanned Aerial Vehicles (UAVs) become a viable option in research due to being cost-effective platforms (de Reu *et al.,* 2014) instead of using helicopters and aeroplanes, such as what the NMP might use. Not only do UAVs use on-board cameras, they can be used with sensors as their technology develops. In sites of low vegetation, UAVs and aerial imagery can aid in the detection of unknown sites, such as in Stek (2016)'s research in Italy. From the research, Stek (2016) concluded that UAVs are an effective and feasible tool in site prospection and can be integrated within methodologies currently used, especially for sites that are threatened, which is one of the considerations that UNESCO made in its World Heritage Convention of 1972.

Eisenbeiss and Sauerbier (2011) investigated the different modes that are available to UAVs and which work best for image acquisition when applied to photogrammetric tasks. With UAVs there are three acquisition modes: manual, stop mode, and cruising mode. Manual mode is controlled by the operator of the UAV and the individual has control over the camera capture. Stop mode has the UAV flying to a predetermined point where it stops to fulfil accuracy requirements. Cruising mode captures images as the UAV flies, making it rather efficient for large data acquisition. The investigation concluded that manual mode UAVs are more unstable as autonomously (cruising mode) controlled UAVs as the latter uses predetermined flight paths, with set overlap levels and accuracy already determined, therefore marking out when and where image capture takes place at regular intervals to ensure high resolution and high coverage (Eisenbeiss and Sauerbier, 2011).

The comparatively low-cost of UAVs is a positive for their use, especially for investigations and surveys that do not have large budgets or funding in support of the research (Rinaudo *et al.,* 2012). The cost-effectiveness of UAVs in archaeological and topographical surveys is beneficial because of the numerous uses they provide (Ceraudo, 2013) and the high level of accuracy produced (Ilci *et al.,* 2019). Their most basic use is as site detection platforms; UAVS can be used in many types of environment: the accessible and the inaccessible (Stek, 2016; Federman *et al.,* 2018; Ilci *et al.,* 2019). Stek (2016)'s investigation focused only on site identification in easily accessible areas that were thought not to have any sites of interest. By using a small UAV system, the investigation revealed clear and readable information on the presence of previously unknown subsurface features by capturing crop marks in the pastures of the Tappino Valley, Italy.

UAVs can play a large role in conservation of heritage sites and buildings. Federman *et al.,* (2018) looked into the surviving buildings of Nepal after the Gorkha earthquake in 2015. UAVs have the potential to be used as post-disaster documentation platforms when accessibility has been hampered by natural disasters and transporting in high cost equipment is a major concern and often a problem (Federman *et al.,* 2018) and from that could aid in the continued documentation and restoration of damaged buildings and structures. UAVs can also be used for the mapping of large archaeological sites; Ilci *et al.,* (2019) concluded that the usability of inexpensive UAVs for site surveying can produce results with centimetre to decimetre levels of accuracy, and the imagery works particularly well in open areas of larger sites in Turkey. This supports the application into landscape archaeology by mapping out swathes of land which can then be utilised in other software for further analysis (Bewley, 2003; O'Driscoll, 2018), then can be added into archives and repositories due to highly precise three-dimensional models, orthomosaics and DTMs (Erenoglu *et al.,* 2017). From there, archaeologists have been delving into the use of three-dimensional modelling and digitising heritage sites for documentation, which could become a standard documentation technique (Lai and Sordini, 2013; Campana, 2017), and digitization is becoming a key concept of preservation (Pletinckx, 2009). It is known that using aerial imagery gathered from aeroplanes and helicopters is a large expense, and as a result UAVs are a cost-effective alternative (de Reu *et al.,* 2014).

2.6.4 Why Monitoring Matters

As has been explained, UAVs have the ability to be a versatile and cost-effective platform to monitor heritage sites (Ilci *et al.,* 2019), especially when the gathered data can be used in other software to create imagery that display areas of concern, such as erosion damage. Themistocleous (2020) stated that documentation of cultural heritage is labour intensive and expensive, and went on to say that UAVs are an innovative, sustainable and more efficient documentation method. The documentation, mapping and monitoring of heritage site health are amongst the main aims of documentation (Ilci *et al.,* 2019), and most importantly, they are non-invasive (Themistocleous, 2020) which is typically unavoidable in archaeological excavation – however, they are collecting very different data than is collected during an excavation; for sites that are being left alone for the future or have no been excavated in some time, drone-derived data collection is non-invasive and should not harm the heritage.

Magnani and Schroder (2015) used a UAV to determine areas of erosion on Hopewell Culture mounds in the USA. The larger mounds are documented more thoroughly than the smaller ones are, but these smaller mounds are just as susceptible to erosion damage and should also be documented for historic site records. UAVs have the potential to become critical equipment in the preservation and monitoring of heritage sites. Combining photogrammetric techniques with more traditional methods can be highly advantageous for performing spatial analyses on heritage sites: Image Based Modelling (IBM) and Low-altitude aerial photography (LAAP) create a workflow that allows for precise, accurate recording of photographic and elevation data (Howland *et al.,* 2018).

O'Driscoll (2018) uses UAVs in his three case studies in Ireland and Scotland; from it he identified previously unknown features at Cahercommaun fort, Co. Clare, Ireland, including hut structure remnants. Despite the issues surrounding using only aerial photogrammetry, micro-topographic features, no matter how faint they are, can be exaggerated in GIS software in order to enhance them in an image, and the exaggeration extent can be controlled by the user and documented to inform viewers that the exaggeration has taken place (O'Driscoll, 2018). Aerial photogrammetry can also clearly display cropmarks when the soil conditions and weather are suitable, but Normalised Difference Vegetation Index (NVDI) cameras do out perform standard aerial imagery in this regard (Gonzalez and Hernandez, 2019); LiDAR cannot do the same without use of intensity data. When orthomosaic images are collected of a nearly destroyed site, such as Glanbane, new features were identified such as the confirmation of bank heights and width, and the discovery of an entrance (O'Driscoll, 2018). This can all be done within hours or days of data collection and guide further investigations into sites that are suffering (Howland *et al.,* 2018) or for overall monitoring of sites to observe any changes in the landscape and heritage health; Bewley (2003), however, suggested that change can be negligible at earthwork sites, but the UAV allows for a cost-effective monitoring system that can be used as often as is needed.

Monitoring does not solely mean protecting sites that have already been found, but those that have gone undetected or overlooked. Sites and features are continually discovered; over summer of 2018 in the United Kingdom, new sites that have been hidden for hundreds, if not thousands of years, have been discovered thanks to the severe two-month heatwave. Prehistoric settlements, burial mounds, Iron Age, Bronze Age and Roman farms have been revealed. Neolithic cursus monuments – one of the oldest types of monument in England, dated to between 3600 and 3000 BCE – have also been found (Historic England, 2018e). These are not earthwork features and do not protrude from the ground, they were discovered through the use of aerial imagery from both aeroplanes and UAVs, such as the Knights Templar road (Figure 2.1) that was found outside Keele University in the same heatwave and was photographed by a UAV (Keele University, 2018).

Figure 2.1: The Knights Templar road, photographed using a DJI Phantom 4 UAV near Keele University, during the summer heatwave of 2018 (Image credit: Dr Alexandre Nobajas)

Monitoring is imperative because features, heritage sites and buildings managed by organisations such as UNESCO, as outlined in *Section 1*, are invested in preserving heritage, both urban and archaeological, for all countries and peoples across the world, and use them to create better, more sustainable policies as part of the Sustainable Development Goals (UNESCO, 2013; United Nations, 2015; Xiao *et al.,* 2018). These features and heritage sites often impact the identity of a nation, therefore the goals to protect urban heritage, and the older Convention of 1972, are to safeguard cultural heritage and cultural property. Objects and archaeology have often become symbolic to nations, such as the Obelisk of Axum of Ethiopian origin which was taken on the orders of Benito Mussolini in 1937, and was placed in Rome’s Piazza di Porta Capena; Ethiopia had been asking for its repatriation since 1947 (Roussin, 2003) and it was finally returned in 2005. This completed the site and made the cultural landscape more meaningful to the country (Mariam, 2009).

2.7 Modelling Techniques and GIS Visualisation Tools

There is a variety of available ways to generate 3D digital models from photogrammetric data, which will be outlined in this section such as Image Based Modelling, Multi-View Stereo and Structure from Motion. Following that, the tools available in GIS software, both open sourced and licensed, alongside some others not directly inside GIS software will also be discussed as to their uses.

2.7.1 Image Based Modelling, Multi-View Stereo & Structure from Motion

Image-Based Modelling (IBM) is a 3D modelling technique that has been in use for many years and is widely utilised for geometric surfaces of architectural objects or precise terrain and city modelling (Remondino and El-Hakim, 2006). The method includes photogrammetry, and uses 2D image measurements to recover the 3D object through mathematical models (Tan, 2014), or from several other aspects such as shape from shading (Horn and Brooks, 1989), and shape from texture (Kender, 1981) to create a geometric shape with a texture map overtop (Tan, 2014). Though widely used, it can be difficult to recover a complete, detailed, accurate and realistic 3D model from images, especially for larger sites (Remondino and El-Hakim, 2006), however in the same investigation, the various data acquisition types, processing and visualisation of 3D data are all from sensors or equipment that is much cheaper than laser scanning, and are also more portable. However, Fernandez-Hernandez *et al.,* (2015) concluded that IBM is an effective and low cost tool that produces high-resolution imagery of complex sites, but this was likely due to improvement to equipment over the last decade.

Multi-View Stereo (MVS) is several algorithms that construct a three-dimensional model from images that have known parameters (Furukawa and Hernandez, 2015) using a plausible geometry that is meant to explain the images under what are termed ‘reasonable assumptions’, such as scene rigidity (Furukawa and Hernandez, 2015), and these images will have known camera viewpoints (Seitz *et al.,* 2006). The algorithms utilised have key properties but are not all the same, and have not commonly been compared due to a lack of datasets that were calibrated with known ground truth (Seitz *et al.,* 2006). MVS essentially takes photographs from viewpoints between two images to increase the robustness for noise and texture (Furukawa and Hernandez, 2015). Techniques of MSV are incorporated into Structure from Motion (Harwin and Lucieer, 2012).

Structure from Motion (SfM) applies photogrammetric principles to photographs taken with a digital camera to generate a three-dimensional point cloud, which are identified feature points – or matching pixels – from across multiple photographs through comparison of intensity and the characteristics within the captured surroundings (Howland *et al.,* 2018). It 'draws out' the 3D shape from within the photographs (Aicardi *et al.,* 2018). These, alongside data containing camera settings and GPS collected with each photograph, allow the algorithm the SfM uses – known as factorization algorithm (Tomasi and Kanade, 1992; Ackermann, 2014) - to calculate relative locations of each image and create a sparse point cloud (Howland *et al.,* 2018). It operates along similar lines to stereoscopic photogrammetry, meaning a 3D structure can be generated from a set of overlapping, offset images, but SfM is fundamentally different from conventional photogrammetry because geometry, camera positioning and orientation is automatically solved without needing a network of known 3D positions (Westoby *et al.,* 2012; Furukawa and Hernandez, 2015; Aicardi *et al.,* 2018).

SfM and MVS can outdo all other recording methods by cost, detail and accuracy; they are amongst the best methods of practice for high quality 3D modelling with photogrammetry (Sapirstein, 2016). This is contrary to what Green *et al.,* (2014) believed of SFM; whilst helpful in modelling, there were still some hindrances that kept it from being advantageous, such as it not being as accurate each time. Green *et al.,* (2014) concluded that it is best as a supplementary tool to photogrammetry, though it is in a strategic spot, balanced between expensive technology and slower, traditional techniques; it was a technology in its infancy and it just needed to improve on its failings to become a highly accurate measurement tool. However, Hesse (2015) suggested that SFM can create high-resolution 3D datasets from imagery that can be used to sufficiently document damage to heritage in arid environments.

SfM is a rather inexpensive platform, and can produce comparable point clouds and point densities to LiDAR data, with both horizontal and vertical precision down to centimetres, all for very low labour costs and no high level expertise in the use of it (Fonstad *et al.,* 2013). For mapping topography from low-altitude platforms, SfM can generate accuracy and precision similar to LiDAR, if not better, for non-vegetated or little vegetated surfaces (Fonstad *et al.,* 2013). Howland *et al.,* (2018) agrees with this assessment; in their investigation Image-Based Modelling (IBM) allows for highly precise and accurate DEMs, even rivalling laser scanning when in certain environments or searching for certain features that it cannot pick up like cropmarks (Howland *et al.,* 2018).

2.7.2 GIS Visualisation Techniques

There are many types of visualisation techniques that can be used, and some of the easy to achieve ones are done in GIS capable software. There are hillshade, aspect and slope (Bennett *et al.,* 2012), all of which are tools within GIS capable software such as ArcGIS (Esri, 2018a). O'Driscoll (2018) praised these functions in his research into landscape applications of UAV photogrammetry and modelling in GIS software; the ability to manipulate the height and direction of the 'sun' in the software meant that previously unidentified features were discovered, such as levelled field systems and possible hut structures at Cahercommaun fort, Co. Clare, Ireland, all of which were found using the hillshade and slope tools. Even for very slight or micro-topographic features, the tools within ArcGIS meant that the digital environment could be exaggerated in order to display the smaller features (O'Driscoll, 2018).

Hillshade works by producing a 3D greyscale depiction of a terrain surface, taking into account the sun's relative position for shading (Esri, 2018b). It is a tool that visualises terrain determined by this light source, the slope and the aspect of the elevation surface. It is qualitative and does not give absolute values for height. There are two options for viewing: traditional and multidirectional hillshade. Traditional hillshade uses just one direction of illumination, derived from altitude and azimuth properties to determine the light's position. Multidirectional uses light from six sources to represent the hillshade; this has an advantage in that there is a lot more detail, especially when depicting terrain that is affected by over-saturation or deep shadows (Esri, 2018b). It is because of the ability to alter the altitude of the sun from 0 to 90 degrees – 0 degrees being the sun on the horizon, and 90 degrees directly overhead – and the azimuth – how far north, east, south and west the sun is along the horizon - is why O'Driscoll (2018) suggested that using GIS software was advantageous when using aerial photogrammetry. However, it had two major drawbacks: identifying detail in deep shades and inability to correctly show linear features that lie parallel to the source of illumination (Zaksek *et al.,* 2011).

Slope is another tool within ArcGIS, which represents the change of elevation for a Digital Elevation Model (DEM) (Esri, 2018c). It gives a slope value in degrees for the inclination of each pixel (Jones, 1998). It is popular within geographical sciences, Jones (*ibid.*) defined slope as properties of a plane that is tangent to a point that is on a surface and these properties can be specified as a single normal vector, or as both gradient and aspect simultaneously.

Aspect is the third tool of GIS used in Bennett *et al.,* (2012)'s comparative investigation. Esri (2018d) explained that it identifies downslope direction of the maximum rate of alteration in value from each cell to the neighbouring cell. The values of the output raster will be in the compass direction of the calculated aspect. Skidmore (1989) and Bennett *et al.,* (2012) described aspect similarly, in that it indicates the direction slopes are facing, represented by degrees north of east. It produces better models when used in combination with Sky-View Factor and Principal

Component Analysis (PCA), the latter being a multivariate technique that reduces redundancy in imagery and produces a series of images that represent statistical variety in light levels of original shaded relief images (Devereux *et al.,* 2008; Bennett *et al.,* 2012).

The next two visualisation techniques are more detailed in their outcomes; Local Relief Modelling (LRM) was largely developed for mountainous areas of the world and produces a model that decreases the macro-topography in favour of highlighting the micro-topography (Devereux *et al.,* 2008; Bennett, *et al.,* 2012). It represents small-scale, local elevation changes in an area once large-scale forms have been removed from the data, typically LiDAR derived (Hesse, 2010). As a result, this enhances the micro-topography that would normally be missed, and does not require any set illumination angle, allowing for elevations and volumes to be measured directly (Hesse, 2010). By resampling original DEMs to lower resolutions, known as the trend DEM, and subtracting it from the original, local small-scale features are separated from large-scale landforms; from there LRM was the most expedient modelling technique because the area of study, Knockdhu promontory, Ireland, has negligible horizontal shift in positioning of both positive and negative features (McNeary, 2014).

Sky-View Factor (SVF) is a technique that utilises diffuse light and the product is a depiction of the total amount of light every pixel is exposed to as an often fictitious ‘sun’ crosses the hemisphere above (Kokalj, *et al.,* 2011; Bennett *et al.,* 2012). SVF essentially has a parameter that corresponds to the amount of sky that is limited by relief, and can be used as a general relief visualisation to depict relief characteristics, and is very useful in recognising small scale features in the landscape (Zaksek, *et al.,* 2011).

Zaksek *et al.,* (2011) defined SVF as a tool that used a fictitious light source that illuminated the relief surface from a celestial hemisphere which was centred at the location being illuminated; it was also assumed that there was equal brightness across the hemisphere, there was no other light sources and the curvature of the Earth was neglected over short distances, i.e. less than 10 km. Relief was correlated to a part of the sky that was limited by the relief horizon, meaning a point on a ridge is brighter than at a point at the bottom of a steep valley. SVF ranged from 0 to 1; values close 1 meant that nearly all of the hemisphere was visible – so exposed features like plains and peaks – and values near to 0 were where nearly none of the fictitious hemisphere was visible, meaning low part of deep valleys and narrow gorges (Zaksek *et al.,* 2011). There was one downfall with SVF: buildings that were not concave were not as clear in SVF, except as a small radius, which must be exaggerated vertically.

Brutto and Meli (2012)'s 3D case-study used Shift Technology Laser Scanning (LiDAR), which is a terrestrial laser scanner, and it had a measuring range of 0.6 metres to 120 metres, and was used alongside a topographical survey station, a Leica 1105 total station. This provided co-ordinates for the laser scanning and photogrammetric targets (Brutto and Meli, 2012). The free software this case study used was Autodesk 123Dcatch and created very good models despite the lack of accuracy and it uses 'PhotoSynth' – a web service – to create further 3D models into panoramas and synths.

2.8 GIS Analysis and 3D Modelling

Few projects have conducted any debate on the theoretical impacts of 3D GIS-based research, which is likely limited to the novelty of such and the managing of files and data, but the idea of combining GIS and 3D imaging is not new to the field of geoarchaeology and has been a concept since the 1990s, when the debate emerged for the first time (Landeschi, 2018). Reilly (1991) advocated for a solid-model depiction of archaeological stratigraphy in order to improve visualisation. Gillings and Goodrick (1996) discussed a need for more immersion in GIS to support the relationship between person and place in a digital format, so that cultural and environmental concerns could be effectively studied. They also identified the need to merge Virtual Reality (VR) and GIS to simulate more than imitate reality.

For research purposes, using visualisation techniques like those outlined in the prior section, allows for manipulation of the digital environment of the site or monument, and therefore means views and observations can be made from various angles and illuminations (O'Driscoll, 2018). It allows for comparison and for verification of the 'natural character' of a site (Faltýnová and Nový, 2014). Once the photogrammetry has been collected, for example aerial photogrammetry in particular, the images need to be put through an SFM workflow in order for them to have data to analyse in GIS software; the datasets that are generated from SFM are incredibly useful within GIS, and further analysis as a result is achievable with unparalleled resolution levels (Howland et al., 2018).

Currently, there is no specialized software for archaeologists to study sites in 3D, therefore they use GIS programmes to conduct their work (Soler *et al.,* 2017) and so their knowledge of the software is limited if it is not something they commonly use. However, other researchers have argued that the multidisciplinary nature of this type of research is beneficial; Balletti *et al.,* (2017) believed their results were as incredible as they were simply because of input from other disciplines.

2.8.1 Uses of 3D Modelling

Three-dimensional models in cultural heritage for documentation has increased in recent years (Fazio and Brutto, 2020). They can be imported into GIS software for analysis: of the landscape, areas of erosion, and volumetric calculations. The 3D models generated from IBM, MVS and SFM can be used further: virtual archaeology or ‘cyber-archaeology’ (Forte, 2019) and as physical 3D printed models (Scopigno *et al.,* 2017), and could be crucial to rapid salvage, restoration and preservation of heritage sites (Meyer *et al.,* 2015). 3D mapping and aerial maps can be highly accurate when created from UAV aerial imagery, and is becoming a global tendency according to Ilci *et al.,* (2019), and they concluded in the same study that 3D models can open up new research areas because they can become multi-layered, interrogable models.

Fast and efficient digitization is growing in demand in archaeology as it is a promising approach for reconstruction of objects (Santos *et al.,* 2016). Cultural Heritage (CH) has been modelled for many years, and interactive 3D sites have been used in programmes such as Microsoft Encarta, which no longer exists as a piece of software (Cohen, 2009). As technology has developed free software is available to use for 3D imagery, and this has been taken advantage of for CH (Guarnieri *et al.,* 2010). Virtual Reality (VR) on web-based systems can serve as a storage of 3D models of cultural heritage, whilst disseminating information about the heritage site in a way that is appealing to younger people on a platform they recognise and use (Anderson *et al.,* 2009).

3D models can be utilised in game engines in order to present it in a new avenue of research because of the continually improving graphics, augmented realities and artificial intelligence that can be added to a scene in order to bring the history and site to ‘life’ insofar as archaeologists can interpret or theorise; a concept that Rua and Alvito (2011) meets the objective of ‘living the past’. Richards-Rissetto *et al.,* (2012) used a Kinect™ device from the Xbox 360™ developed my Microsoft (Microsoft, 2019) to create a low-cost and portable system that uses VR to navigate a prototype 3D GIS digital reconstruction of the UNESCO World Heritage site Copan, a Mayan city. The 3D GIS software named 'QueryArch' was developed as part of 'MayaArch3D', which is project that explores the potential of combining databases and 3D digital tools for research and teaching of ancient landscapes and sites, whilst simultaneously creating a sense of spatial awareness when not using a keyboard or mouse (Richards-Rissetto *et al.,* 2012).

2.8.2 Why Digitisation Matters

Firstly, digitisation is the process of conversion of material into digital form (Muenster, 2022), which is the technical transfer of an object to a digital asset. 3D reconstruction, however, is the process of human interpretation of data to hypothesise of a past incarnation of an object or feature (Muenster, 2022). Digitisation is explained more in this section, and 3D reconstruction shall be covered in Chapter 6. Digitisation has the potential to become a standard documentation technique in archaeology (Lai and Sordini, 2013) but beyond that, heritage sites – as outlined in this chapter - are under threat, and need to be cared for and monitored if future generations are to enjoy them, as per UNESCO's direction. In Howland *et al.,* (2018)'s investigation, they used Low Altitude Aerial Photogrammetry (LAAP) and Image-Based Modelling (IBM) to create DEMs which could then be utilised in GIS software in order to model the effects of erosion at archaeological sites. At earthwork heritage sites, erosion is to be expected, but it does need to be managed whether natural or manmade, such as at Arbor Low in the Peak District (Figure 2.2).

Figure 2.2 Damage at Arbor Low on the round barrow in 2020, likely caused by excavation and exacerbated by livestock and people (Image credit: Helen Malbon/Alex Nobajas)

It is imperative as per the UNESCO SDGs and the UNESCO World Heritage Convention 1972 that heritage is preserved (Soler *et al.,* 2017). Digitising heritage sites can be a support to cultural heritage for visual presentation, documentation, communication and education (Mortara and Catalano, 2018). Websites such as *SketchFab*, *Tdar* and *3D-Hop* allow for content creators to upload 3D imagery of real-world places, meaning all types of people – researchers, students and the public – can browse them easily, and see well-made 3D images; the core of interest is not solely about the models themselves, but interaction that can be gained through use (Forte, 2019).

These websites also provide their own tools for simulation, annotation and collaboration: Virtual Reality Modelling (VRM) in 'cyberarchaeology' – which became an accepted discipline in 2010 – focused on these three aspects and the potential to formulate new research questions from it (Forte, 2019). In brief, cyberarchaeology is multimodal 3D simulation and interaction revolving around archaeological datasets in differing domains, which is growing continuously (Forte, *ibid.*) as 2.5 quintillion bytes of 3D data was made every day as of 2019, 80% within the last two years, meaning that archaeology was part of a revolution in technological change.

However, as Khalaf (2018) identified, reconstruction has been considered "*irrational and inappropriate*" (UNESCO, 1976, Preamble) and a "*denial of the history of a site*" (UNESCO-WHC, 2005, pg. 4), therefore, it was frequently considered to be appropriate only in exceptional circumstances. Therefore, the same could likely be said for any digitisation of contemporary sites, but Khalaf (2018) argued that today's world often put sites in danger of destruction through exceptional circumstances, i.e. armed conflict and natural disasters, consequently the concept required re-examination. From that is establishing how best to present reconstruction, as Virtual Reality and 3D modelling may be a good methodology, but the next step is how to classify these digital models or reconstructions of heritage.

Subsequently, there are considerations that could impact digital visualisations; in 32 charters, Statham (2019) found that merely two focused on broad scientific guidelines for virtual and visualising heritage. These are the London and Seville Charters, but both are high-level principles more concerned with authenticity and scientific rigour (Statham, 2019; Falconer *et al.,* 2020). The London Charter sought to have ground rules for visualisations, in order for there to be greater liberty, the methodology has to be precisely recorded, be transparent, for researchers; an aspect of a building may be visualised, but without considering and informing that it is a part of a larger whole, the visualisation is incomplete – this is a "*hypothesis machine*" (London Charter, 2009, pg. 68).

Unger *et al.,* (2020) acknowledged there are risks to using VR to present heritage; as archaeology and the sites involved are inherently incomplete, the interpretation or reconstruction is ambiguous. This left visualisations with a high degree of uncertainty – this uncertainty being why some researchers do not always fully believe that VR should be used to any great extent for reconstructions of heritage sites. The London Charter did specify that reconstructions should be accurate in determining the differences between real data and hypotheses, and levels of probability (Unger *et al., ibid.*). This will be discussed further in Chapter 6.

2.9 Conclusion

It is clear by actions of UNESCO, national and regional efforts in countries across the world that heritage preservation is of great importance. Heritage becomes part of cultures and landscapes, as has been explained in this chapter, and the loss of them by whatever means, impacts the value of a landscape and the people to whom they meant something, tangible or intangible. Heritage is part of the historicity, a key part of landscape character values (depth of time, historical richness and continuity) and to lose them would lower the value of the landscape, especially if lost to human encroachment.

Digital documentation could serve earthwork heritage monuments as they are susceptible to erosion damage from tourism, agricultural practices and naturally occurring processes that impact landscapes at large, both natural and manmade. Whilst digitising would not save a heritage site directly, it would at least save the existence of it in the digital form to be see again if ever it was lost wholly. UAV-derived imagery appeared to be the most suitable to demonstrate monitoring, particularly due to the research into effectiveness of aerial photogrammetry and LiDAR-derived data; in fact, in particular environments, i.e. low vegetation landscapes, UAV imagery is as good as LiDAR data and not as expensive, comparatively. UAVs, as will be explained in more detail in Chapter 4, and has been briefly discussed in this chapter, are cost-effective data gathering platforms in comparison to satellite-derived data, and they are available commercially and for research. Using the gathered data from a UAV, the imagery can be modelled utilising specialised software like AgiSoft to create photorealistic models and DEMs, that latter of which can be used inside GIS software for analysis, the intent of this investigation, and will be discussed in more detail in Chapter 4.

GIS software has been used in archaeology since the 1980s, and has been used in geography and related disciplines for as long, and there are visualisation methods from within the subject that could be of use to archaeology beyond merely mapping settlement distribution. The change of contemporary sites is as important as using UAVs and 3D modelling to capture an ongoing excavation alone, and the damage at extant sites is in need of effective surveying, visualising and documenting that can be afforded with GIS and UAV used together.

Whilst rebuilding a heritage monument to replace a damaged one is of some contention and only allowed under certain circumstances, to rebuild one digitally is of increased research and educational benefit to all people; from researchers to the public. The main question is how to go about it in such a way as to remain appropriate, and is this even possible? There are researchers that would suggest they are hypothetical, even if the DEMs and models are of contemporary sites, they are not the true piece of heritage. However, 3D imagery and VR technology could open new avenues of research that may potentially immerse a researcher in a world they wish to investigate in ways that have been limited in the past due to contemporary technology. As technology evolves, so too can ways of understanding and benefiting for heritage sector at large.

The uses of the outputs created from UAV and GIS data reconstruction will be discussed in Chapter 6, but in brief, 3D models can be utilised in more than just research, but on platforms that are accessible to the public such as video games, interactive exhibits in museums and online. Also, since the COVID-19 pandemic, when people had to stay at home, they can be used for home-schooling on history and heritage in a similar manner. Beyond that, there is also the use for disabled individuals who cannot access these sites physically, to partake in heritage the same way the general public can. Again, this shall be discussed in Chapter 6.

Chapter 3 Wider Landscape of the Study Sites

This chapter is dedicated to explaining the locational context of the sites in this investigation (Figure 3.1). The best authority on the history of the Peak District National Park (PDNPA) is John Barnatt, a senior archaeologist for the PDNPA (PDNPA, 2022), and his invaluable works and surveys are cited throughout. To understand in far more detail than is covered in this chapter, his works are best referred to.

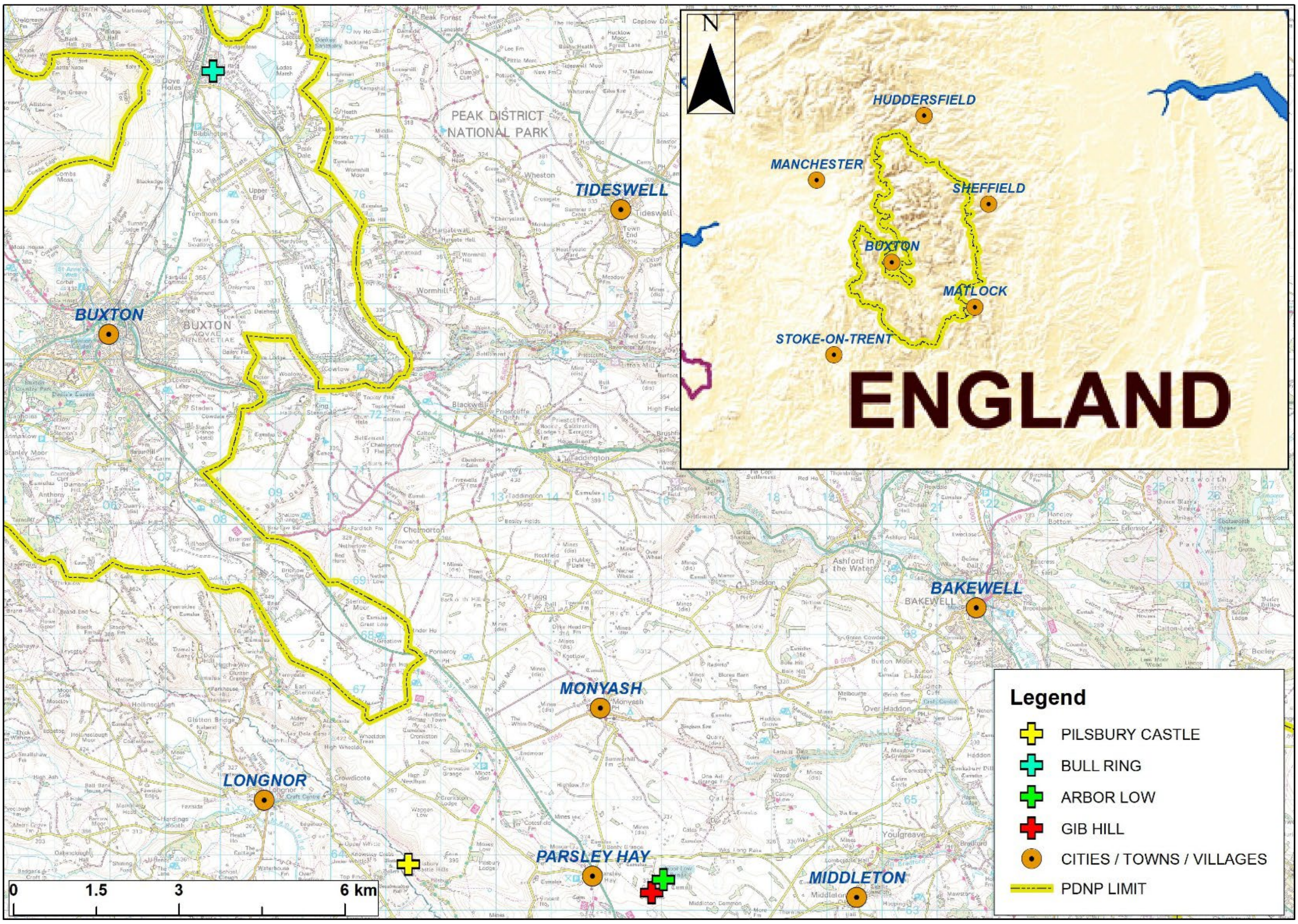


Figure 3.1: The sites of investigation in the wider context of the Peak District National Park (yellow dashed line) (adapted from Edina Digimap, 2018)

Four sites were selected for this investigation, all exhibiting signs of damage accrued over long lifetimes. The oldest are Gib Hill, Arbor Low and Bull Ring, dated to around the 3rd millennium BCE; these are two henges and a long/bowl barrow. The youngest site is Pilsbury Castle, an 11th century Norman motte and bailey castle. All are situated in or near the Peak District National Park, 1,438 square kilometres that extends from Derbyshire, Staffordshire, Cheshire and the south of Yorkshire (Peak District National Park, 2020a). The most frequent monument type in the Peak District is the round barrow, with several hundred documented, and dated to the later Neolithic and Early Bronze Age; 5,000 – 4,500 BCE and they were built in a variety of forms (Barnatt, 2019). The earliest barrows were likely small in size and surrounded by stone chambers, but later forms of design diverged down two main trends. In the first, barrows were enlarged with chambers added, such as Minninglow; it is 45 x 38 m and has evidence of at least five chambers (Barnatt, 2019). Minninglow can be seen from Arbor Low and Gib Hill to the southeast (McGuire and Smith, 2008).

The second of the two trends was to make them longer, for example Gib Hill: it was a short oval barrow with no stone chamber (Barnatt, 2019). Long Low, a barrow near Wetton, Staffordshire is an exceptional example: a 210 m long bank barrow where 13 individual skeletons were found, and more with the drystone wall on the old ground surface; several limestone slabs were placed either side of the wall to form the mound, which Barnatt (2019) suggests may mean things were done differently in Staffordshire. The size, date and its creation makes in comparable to the henges (Barnatt, 2019).

3.1 *Wider Landscape: The Peak District*

In order to understand the setting and history of these four sites that fall within or just outside the boundary of the Peak District National Park (see *Appendix C*), the landscape that makes up the Peak District must be described and understood briefly, but to better understand these areas in far more depth, see Barnatt (2019)'s work, information on the Peak District National Park website or from various other works by Barnatt over his career.

3.1.1 *The Regions of the Peak District*

The Peak District was the first National Park in the UK, founded in 1951 (PDNPA, 2020a) and covers approximately 1500 square kilometres (Edensor, 2017) across Cheshire, Staffordshire, Derbyshire, Yorkshire and Lancashire at the southern end of the Pennines. It is described as having a "*host of vibrant visual contrasts*" (Barnatt, 2019, pg. 1), by Edensor (2017) as variegated and by the PDNPA itself as a beautiful setting, enjoyed by over 13 million every year (Peak District National Park, 2020a). The entirety of the Peak District has a long sense of time within, from the White Peak farmland, the Dark Peak moorland, and the deep valleys that separate them (Barnatt, 2019), and due to the upland nature it has meant plenty of history has survived over centuries, as a result there are many Scheduled Monuments spanning thousands of years in age (Heathcote, 1957; Barnatt, 2019). Today, the park is a popular tourist destination: a Peak District National Park Authority (2014) survey found that 79 % of visitors were day visitors, and two-thirds were regular visitors. Nearly 10 million people visit every year and half the population of England and Wales live within 60 miles of the Peak District (Edwards, 2017).

There has been a longevity to its tourism; antiquarian William Camden wrote in his *Britannia* (1586) of nine 'wonders' to be found in the Peak, yet he considered a mere three of them significant; Michael Drayton's topographic poem *Poly-Olbion* (1622) described seven 'wonders' on an accompanying map; and Thomas Hobbes wrote another poem, *Song of the Wonder of the Peak* (1678) in honour of his visit to Chatsworth, that enhanced popularity for the area. Yet, not every person agreed with Hobbes' perspective as some agreed with Defoe in his 18th century travel writings that some of these wonders were not so wonderful; "*…great cave or hole in the Earth, called Poole's Hole, another of these wonderless wonders,"* (Defoe, 1727, pg. 58), however he had earlier described it in a perhaps more flattering light as a "*houling [sic] wilderness"* (Defoe, *ibid.*, pg. 44), but whether this was complimentary is uncertain.

There is debate over what is distinctive and valuable in the Peak District, and this has become one of its defining characteristics (Edwards, 2017). Edwards (*ibid.*) went on to suggest that it was due to the contemporary accessibility and the multitude of visitors that has contributed to this uncertainty about the value; Marson *et al.,* (2009) even proposed that the cultural identity is something not confirmed nor articulated. However, Edwards (2017) offered a view in contrast: this lack of definition can be viewed positively and the identity is multi-layered and plural, and that tendency towards plurality is in the representational heritage.

Typically, the Peak District is split into three regions: Dark Peak, White Peak and South West Peak (Edensor, 2017) (see *Appendix C*), but Barnatt (2019) proposed that dividing the Peak District into just 'White Peak' and 'Dark Peak' was too simplistic, yet they are utilised to highlight the major geologic and environmental contrasts. In reality, the Peak District can be divided into five main regions (Barnatt, 2019):

- White Peak – the central limestone plateau stretching from Alstonefield, Staffordshire to Buxton, Derbyshire; all four sites of investigation fall inside or on the fringes of this area
- Dark Peak - north from Chapel-en-le-Frith towards Huddersfield
- South-West Peak – nearly all of the Staffordshire Peak District, including the Roaches
- Shale Valleys – valleys containing the Rivers Derwent and Wye, a division between the White and Dark Peaks on the eastern side

- Southern Valleys – stretching between Ashbourne and Wirksworth, and culturally part of the Peak District

3.1.2 White Peak

The White Peak is geologically defined as the large limestone plateau in the heartland of the Peaks that holds a great time depth as fields echo a medieval past that were enclosed officially in the 18th and 19th centuries (Barnatt, 2019; PDNPA, 2020f). In contrast to the Dark Peak, the limestone valleys, hills and dells are primarily focused on dairy and arable farming (Edensor, 2017); trees grow in steep-sided dales that contrast with the limestone plateau cut by glacial meltwater channels (PDNPA, 2020e; 2020f), and wide, green fields as the limestone plateau through history has been a centre point of pastoral farming (Barnatt and Smith, 2004). Arbor Low and Gib Hill are directly situated inside the plateau near the villages of Monyash and Middleton-by-Youlgreave; the Bull Ring is situated on the northern fringes at Dove Holes near Buxton, and Pilsbury on the western edges close to the Staffordshire border. The White Peak is largely Carboniferous (Visean stage) limestones (Hose, 2017) that comprises the large plateau on which Arbor Low and Gib Hill sit, and the Bull Ring is on the fringes of. The dales are steep-sided and contrast with the “rolling limestone plateau” (PDNPA, 2020e) that were cut by glacial meltwater channels (PDNPA, 2020f). Large portions of the White Peak limestones, around 50 km², have been dolomitised, particularly the coarse-grained facies (Ford, 2002).

It has a high rolling top with steep drops at the edges, the rivers have eroded steep-sided valleys such as the Wye, Lathkill near Arbor Low, Dove and Manifold (Barnatt, 2019). The side valleys were largely used for grazing and as pastureland, above the gorges are broad with shallow upland basins before them, consisting of rich, shallow soils (Barnatt, 2019). The plateau rises from shallow upland basins that have been previously cut by many dry valleys that lead to steep, precipitous gorges that drain to the east and south (Barnatt and Smith, 2004). The highest points rise to 450 m in the west and north of the plateau, and the rivers commonly have flat-bottomed shelves above them that are pre-glacial cut by the gorges (Barnatt and Smith, 2004).

The water supply and altitude are imperative factors as only a few yearlong watercourses that exist on the plateau such as the Wye, Lathkill and Manifold (Barnatt, 2019). When rainwater falls it percolates underground, and most of the water in these systems flow through caves than at the surface (Barnatt and Smith, 2004; Barnatt, 2019). It re-emerges on the edges of the plateau or at the few natural meres at the surface and some manmade dew ponds available for livestock in fields (Barnatt, 2019). Resultantly, the villages that formed on the limestone plateau were built near to these sources and reliable springs that often follow the outcropping of an impervious volcanic bed in the limestone (Barnatt and Smith, 2004; Barnatt, 2019).

3.1.3 Dark Peak

The Dark Peak can apply, quite simplistically, to any area that is not considered the White Peak, and primarily it consists of the southern Pennines with flooded valleys and reservoirs, stone outcrops, heathland and bogs (Edensor, 2017). The Dark Peak of the northern climes of the Peak District are typically open moorland of coarse heathers, grasses and bilberry; it encompasses Kinder Scout, the highest point in the Peak District at close to 600 m high (Barnatt and Smith, 2004), with scattered farmsteads that farm livestock over crops (Barnatt, 2019).

The eastern moors of the Dark Peak are on average lower in altitude than in the north, and is farmed comparatively more (Barnatt, 2019). It is within the Dark Peak that the famous Stanage Edge, a dramatic gritstone cliff (known as ‘Edges’) (PDNPA, 2020d), can be found; though it was too high for settlements in the past, places like nearby Bamford Moor has evidence of ancient settlements (Barnatt, 2019). There is an interface between the gritstones of the Dark Peak and the limestones of the White Peak that are rather shaley (Barnatt and Smith, 2004); it is on such an interface that Pilsbury Castle was constructed and modified around a small limestone reef knoll.

3.1.4 South-West Peak

The South-West Peak covers most of the Staffordshire and Cheshire Peak District; it is a distinct area with upland valleys, moorland and some pasture land (Edensor, 2017) even though this area can be combined with the Dark Peak for simplicity (see *Appendix C*). In this area, the settlements, typically farmsteads or small hamlets, are more dispersed and many lie on the edges of the limestone plateau of the White Peak, as the valleys here are broad and waterlogged, with some moorland near Buxton and the Bull Ring at Dove Holes. It is an intimate mosaic of hedges, bogs, wood-, grass- and wetland on ridges, slopes and plateaux that are managed closely (PDNPA, 2020c).

Of the Staffordshire villages, many existed in medieval times and likely existed well before that; for example, the village of Longnor was granted a market charter in 1293 (Coates, 1965), and was ‘imposed’ onto the hamlet zone of the plateau-clinging villages (Barnatt, 2019). It is situated between the River Dove and Manifold valleys, and it is very likely that medieval roads led past Pilsbury Castle in the time after the Conquest of 1066.

3.1.5 Shale Valleys

The Shale Valleys are the main valleys in the heart of the Peak District; the River Derwent valley reaches south to the ridges of the River Wye near to Ashford and Bakewell, Derbyshire and the ridges from here extend further south to the Lathkill, near to Arbor Low (Barnatt, 2019). The larger villages of the Peak District tend to follow these valleys in the heartland of the park (Barnatt, 2019). At the interface of shale between the White and Dark Peaks is where the main valleys have formed; the River Derwent has been considered a main artery for the region for millennia (Barnatt and Smith, 2004), whereas Dove and Manifold valleys – both within or near to the shale valleys – are much more isolated due to the limestone in the west. Pilsbury Castle is on such an interface in the Dove Valley.

3.1.6 Southern Valleys

Whilst not quite inside the limits of the park, they are culturally part of it (Barnatt, 2019). It begins at the south end of the limestone plateau steeply to the numerous villages of the area such as Ilam and Blore amongst others (Barnatt, 2019). The valleys in this small region – which is comprised of some of Staffordshire and Derbyshire – run through low and flat-topped sandstone and mudstone hills; in history this area was not as commonly farmed, and was used as a large hunting forest near to Duffield, Derbyshire in the east (Barnatt, 2019).

3.2 Environment and History of the Peak District

On the limestone plateaux, Barnett (2019) described the soil as being thin and acidic, and best on the shelves beside the gorges and gorge-heads (Barnatt and Smith, 2004; PDNPA, 2020e). Elsewhere, the soils are described as heavy clays, and there were glacial terraces in some of the valleys, or on the gritstone scarps and shelf, it was once fertile, but is now stony/sandy soils, after the removal of woodland, these fragile lost soils led the landscape to becoming water-logged and peaty (Barnatt and Smith, 2004; Barnatt, 2019; PDNPA, 2020d). The valleys are boulder-strewn or steep-sided and has impacted how communities have formed and travel between them (Barnatt, 2019).

Humans have likely been exploiting the Peak District for over 500,000 years, as hunter-gatherers with the earliest finds dating to the Palaeolithic, what little was found (Barnatt and Smith, 2004). From 4500 to 2000 BCE, the Peak District was an incredibly important area for grazing and cultivation (Barnatt and Smith, *ibid.*). However, climate has always fluctuated and has impacted periodically on what areas of the Peak District could be farmed; indeed, climatic decline from 1000 BCE contracted arable regions – such as in the Dark Peak areas which became waterlogged and peaty (Barnatt and Smith, *ibid.*) – and nearly reduced the Peak District to a backwater region, but this was later offset by lead mining (Barnatt and Smith, *ibid.*; Barnatt and Penny, 2004).

The last glacial advance in Britain left the highest areas of the southern Pennines free of ice but it was still in Arctic-like conditions, known from evidence inside Dowel Cave in Chrome Hill and Foxhole Cave in the hill High Wheeldon that aided immensely in understanding late glacial and post-glacial environments of the Staffordshire/Derbyshire area of the Peak District (Weston, 2000). Inside Dowel Cave, Bramwell (1959) reported there were remains of late Pleistocene mammals and birds with two flat flint blades, charcoal and fragments from a split deer bone. In

Foxhole Cave were cave bear bones – a forerunner of the brown bear, but not a direct ancestor – and cave lion bones (Bramwell, 1971; Weston, 2000).

By 7600 BCE birch trees covered most of Britain, and the climate continually grew warmer and by 5,500 BCE the weather was warm and dry with milder winters, but it slowly became wetter (Weston, 2000). Mesolithic hunters that came up onto the plateaux crafted microliths, skilfully fashioned small flint blades, as described by Weston (*ibid.*), and examples of these tools were found in Foxhole Cave alongside horse and red deer bones. Around the same time, broad-leaved deciduous trees such as oak, elm, lime and alder became commonplace in the Peak District (Weston, *ibid.*).

For the first farmers, between 4000 BCE and 2000 BCE, the oscillation from glacial to interglacial had reached a warm climax (Barnatt and Smith, 2004), and the flora and fauna were diverse. By 3000 BCE, things became drier again, the winters colder, and humans truly moved onto the plateaux, where there was ash-dominated woodland (Barnatt and Smith, 2004), and evidence of clearing for farming. Settlements developed and nearly forty have been found such as Aleck Low and at Upper House Farm, all dated to the Neolithic (Weston, 2000). Both of these aforementioned settlements are around 4 km south of Arbor Low and Gib Hill, and also the much later feature, Pilsbury Castle. Barnatt (2000) suggested that the creation of Arbor Low and Bull Ring may have been part of a division of farming on the White Peak, due to their similar designs and the likelihood of over-arching socio-political affiliations inside smaller, localised communities.

Farming was not the only ‘industry’ in the area, as was previously mentioned, lead mining offset reduction of the region (Barnatt and Smith, 2004). The Peak District has been mined for thousands of years for the many mineral deposits and ore; for example, to this day there are several quarries that mine lime aggregates and sandstone (Huggett, 2020) – this will be discussed in *Section §3.5.2* of this chapter, briefly, about the impact on one of the sites of this investigation. There are plentiful relic lead mines that are still visible in the landscape today, and other minerals such as calcite, barytes, and fluorspar were also mined (Barnatt and Smith, 2004; Barnatt, 2019), particularly in Castleton, Derbyshire where the fluorspar called Blue John, regarded as unique (Ford, 1994), can be found. This banded blue fluorite is found beneath Treak Cliff near Castleton, formed when the limestone was at a depth of 3 km in the late Carboniferous to Early Permian stages (Ford, 2000). Elsewhere, copper was mined extensively, but has since been worked out; and in the gritstone-dominant areas, high grade sandstone has long been used for construction, and coal has also been mined (Barnatt, 2019). The mineral veins tend to follow faults and trend east to west (Barnatt and Smith, 2004).

There is an uncertainty around what the impact of global warming will actually be, however Barnatt (2019) theorised that there will likely be an increase of arable farming that will change the landscape. People, on the other hand, have been changing the Peak District since the last glaciation 10,000 years ago though the people were mostly likely hunter-gatherers for the first 5,000 years (Barnatt and Smith, 2004), and it was said by Barnatt (2000) that prehistoric farmers were still farming in the East Moors long after it was thought to have deteriorated sometime in the first millennium BCE (1000 BCE to 1 BCE).

3.2.1 *Prehistory to Bronze Age*

Three of the four sites in this investigation are inside the White Peak – Arbor Low and Gib Hill – or on the fringes – Bull Ring - and were built in the 3rd millennium BCE (Edmonds and Seaborne, 2001). The differing regions of the Peak District are not only different geologically but also environmentally, as they have different vegetation and habitats. For prehistoric farmers, the landscape of the Peak District would have been much different than it is today with a diversity in flora and fauna (Barnatt and Smith, 2004).

It was not long after people moved onto the limestone plateau that Gib Hill was constructed, sometime between 4,000 and 3,000 BCE, followed by Arbor Low, as evidence of Neolithic farmers were entrenched by 3,500 BCE (Weston, 2000). The builders of the monuments perhaps did not see them the way researchers do today, and did not see a separation between the practical and the spiritual when building (Barnatt and Smith, 2004). It is possible they were used for rites of passage, spaces where the everyday routines were not part of it, but was simultaneously not of significance in the way modern conception of spiritual places are seen (Barnatt and Smith, 2004); they may even have been built to celebrate natural cycles of transformation, such as seasons.

Some of the earliest earthwork monuments that have survived are chambered cairns and long barrows (Barnatt and Smith, 2004). The height of farming in prehistory ranged from 4500 to 2000 BCE, and this coincided with the construction of many of these monuments; there are eight examples of chambered cairns in the Peak District built from large stone slabs and drystone walls (Barnatt and Smith, 2004). Some were closed boxes whilst others had low passes leading away from the mound edge, and the oldest were small and circular, with one or two chambers (Barnatt and Smith, 2004). Later cairns, on the other hand, had larger mounds and contained more chambers, and there exist at least five certain long cairns with no internal chambers, with three examples of superimposition of later burial mounds onto an older cairn (Barnatt and Smith, 2004). An example of this superimposition is seen at Long Low in Wetton (Figure 3.2), Staffordshire (Barnatt and Smith, 2004) and at an investigation site: Gib Hill.

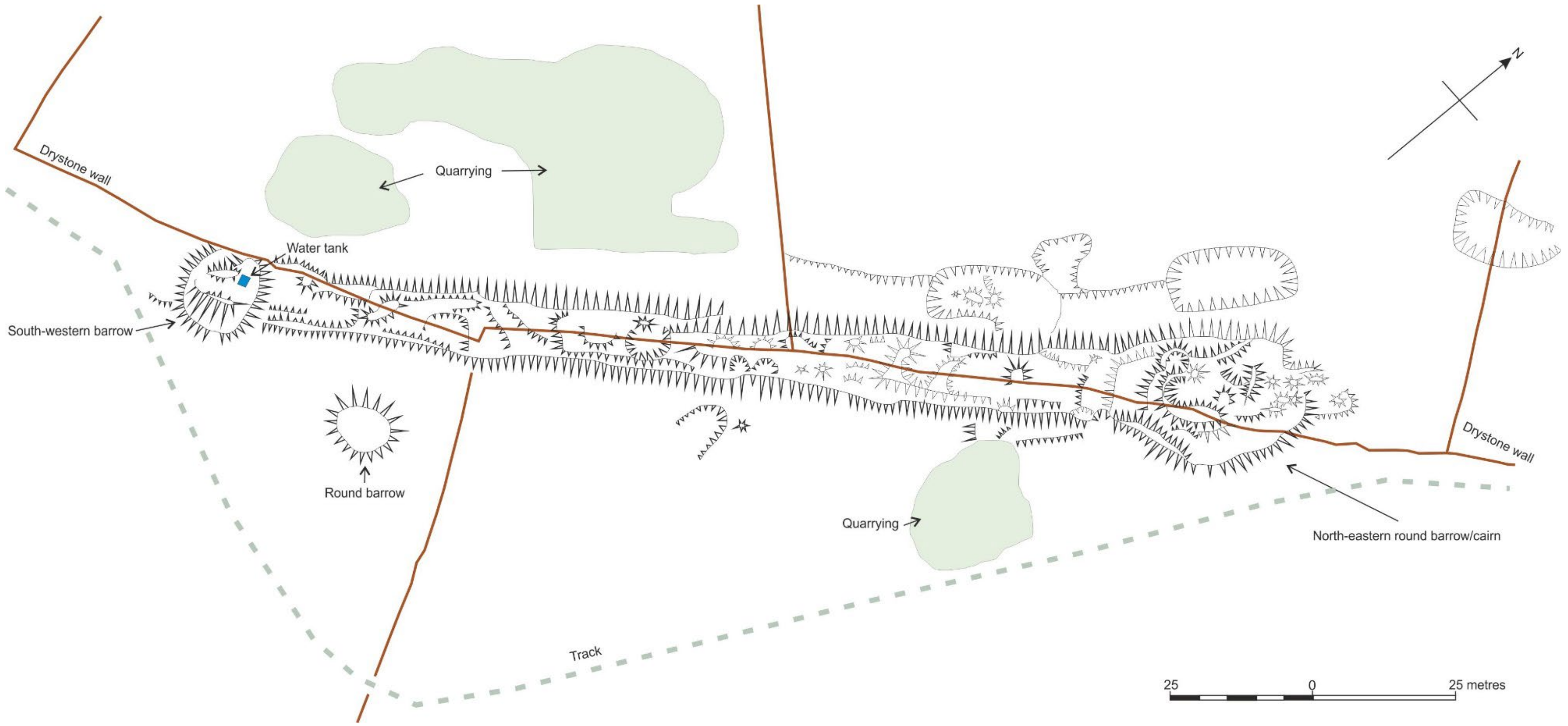


Figure 3.2: Adapted from McOmish and Tuck (2002), from a survey completed for English Heritage, a hachure plan of Long Low, Wetton, with superimposition at the south-west and north-east ends of the long barrow of younger round barrows/cairns.

Rogers (2013) proffered that between 348 and 467 barrows were extant, with 140 to 203 since lost, but Barnatt and Smith (2004) suggested 500 round barrows were known to exist dated to 2500 to 1500 BCE. They were built from earth and stone, commonly circular and measured 30 m across, but are now grass-covered when once they may have been a white feature on the landscape (Barnatt and Smith, 2004). Present at some barrows was evidence of ditches, but they have since been silted up; in other cases, the barrows were enlarged over time and through use (Barnatt and Smith, 2004). Bodies were often found laid on their sides, in flexed or foetal positions, and it appeared that the mounds were often built after several burials had already occurred (Barnatt and Smith, 2004). Some thought had been put towards the idea that they were not strictly burials but rather used for bone storage - the bones being removed for ceremonies – and used as a form of showing tenure over land; the barrows contain bones of the communities' ancestors, therefore this land is theirs (Barnatt and Smith, 2004).

There are many barrows and cairns constructed on the limestone plateau, and this may have been because of the presence of settlements, or in regard to phenomenology, explained in *Chapter Two*, there was a particular perception of the landscape for burial and bone storage (Barnatt and Smith, 2004). Topography and location are quite likely to have determined where monuments such as Gib Hill and Arbor Low were built (Barnatt and Smith, 2004), as in their case, Arbor Low was not the initial focus on the crest, but the superimposed long barrow, Gib Hill. Sadly, nearly all the long barrows have been robbed of their grave-goods but for each one, the internals were different, suggesting that the community oversaw how the insides were constructed (Barnatt and Smith, 2004), though the external was homogeneous with all other cairns and barrows.

Other, smaller features that have survived are stone circles: there are around 26 examples of stone circles in the Peak District built around 2000 BCE with small upright stones inside inner banks, and these stone circles are common features across England and North Wales (Barnatt and Smith, 2004). Both the stone circles and the henges were likely communal, though as previously mentioned, the henges would have held larger numbers, if not most, of the local people (Barnatt and Smith, 2004). The smaller stone circles may have been for smaller gatherings because they were also built as circular structures, perhaps to enforce the concept of a communal identity – this is reflected in architecture dated 3000 to 1500 BCE across England, to reflect community rather than a hierarchy (Barnatt and Smith, 2004), as these sites needn't necessarily be considered and understood within the framework of hereditary elite families, but potentially built from desires of the wider populace (Barnatt, 2000).

Strong arguments were also put forward that there may be an ethnographic reason for the construction of rings in circles: they often looked impressive on natural topography and at certain times of year, such as solstices, and with the rise and setting of the sun behind stones or hills (Barnatt and Smith, 2004). These structures – henges and stone circles – appeared to have held the living, and built in accordance to certain field systems – this is seen in the eastern moorlands where stone circles appear to have direct association with field systems there; this implies that there may have been a stone circle, and a barrow too, for each community (Barnatt and Smith, 2004). Due to the fact much of this prehistoric landscape can be reconstructed allows for such insights into the construction of the communities here: they had barrows constructed at a distance on topographical boundaries such as watersheds or points that overlook farms, small stone circles and field systems attached to each (Barnatt and Smith, 2004).

Alongside the barrows and stone circles are the henges. They have been dated to the Later Neolithic (3000-2000 BCE) and follow similar measurements and design, with banks and internal ditches (Barnatt and Smith, 2004) and was likely used by nearly everybody in the area. Currently, Arbor Low still has its internal stones, but the Bull Ring's had been removed some time in the 18th century, likely for agricultural or construction requirements in the local area (Barnatt and Smith, 2004). Bradley (2011) argued that the stones within Arbor Low was likely the first henge construction, and then later enclosed by the construction of the embankments and ditches. (Rogers 2013) suggested this was supported by the theory that earlier monuments were revisited and reused over time, and represented a conscious decision to enclose the stones.

3.2.2 Iron Age to Norman Conquest: 1000 BCE – 1066 CE

Romans made it to the Peak District by at least the mid-50s CE into the tribal territories of the Brigantes tribe (Weston, 2000). ‘Brigantia’ was a loose confederation of tribes in most of Northern England, and the Peak District was either part of it or was a buffer zone between it and the East Midlands tribe, the Coritani, who were allies of Rome. Brigantia was ruled by Queen Cartimandua, who was initially friendly to Rome, but this changed when the leader of the defeated Welsh tribes sought protection in 51 CE (Weston, 2000). Her consort, Venutius, rose in rebellion against her in an anti-Roman faction, prompting her to seek help from Rome; they ended the rebellion but they annexed the region due to untrustworthiness (Weston, 2000).

In contrast to the south, Rome kept a military presence in the north until their departure in 5th century CE, implying the northern tribes were not wholly trusted (Weston, 2000) and across the Peak District numerous roads connected Roman forts and settlements – one being the A515 between Little Chester, near Derby (*Derventio*), and Buxton (*Aquae Arnemetiae*), both significant Roman settlements. This road passes near Arbor Low, Gib Hill and Pilsbury Castle before leading close to the Bull Ring.

Following the departure of the Romans in 410 CE there is little known of the people dwelling in the Peak District (Barnatt and Smith, 2004; Weston, 2000). The people living in the Peak District appeared to be of British (pre-Roman) stock, as evidenced by two pre-Anglian places, both named ‘Eccles’ meaning ‘church’, one near Hope and the other near Chapel-en-le-Frith (Barnatt and Smith, 2004). Following the arrival of Anglo-Saxons, there appeared to be linear bank and ditches cut for separation between the native population and the new arrivals; Anglian 7th century graves were mainly up on the southern reaches of the limestone plateau, away from the Hope Valley and these linear bank and ditches (Barnatt and Smith, 2004).

By the 7th century, the Peak District eventually became part of the Anglian kingdom Mercia, the largest kingdom that existed at the time. The Mercian tax account, the *Tribal Hidage*, names a tribe of 1,200 households as the '*Pecsaetan*' or 'Peak Dwellers' (Barnatt and Smith, 2004; Weston, 2000). When, exactly, the Anglo-Saxons arrived in the area is uncertain; earliest evidence comes from 6th century pottery in Carsington, Derbyshire, and a 6th century grave near Ilam, Staffordshire (Barnatt and Smith, 2004). Clearly, there had been a shift from a British ruling elite to an Anglian one (Pecsaetan) but whether this was done through conflict or intermarriage is not known (Barnatt and Smith, 2004), but the population looked to be fairly isolated, discrete though well-established.

The Peak District was mostly left alone from initial raids from the Vikings until the late 9th century; by 867 CE major issues developed when a great army descended on the south of England from York and the Mercian king, Burgred, fled to Rome in 874 CE (Barnatt and Smith, 2004). A Danish army wintered at Repton in c. 874 CE and the Danelaw formed. Though part of the Peak District may have fell under Viking control, the lack of Norse-derived place names suggests a lack of direct impact on the area (Barnatt and Smith, 2004). Eventually, the King of Wessex went against the Viking leaders and in 917 CE the Danish borough in Derby fell, and in 920 CE fortifications – location uncertain exactly – were built in Bakewell (Barnatt and Smith, 2004), and Danish Northumbria fell in 927 CE, Wessex gained control and formed one kingdom.

From this time onwards to pre-1066, the formation of villages occurred; and before the Conquest, much of the land was owned by the King, controlled through Royal Manors, and each had a number of 'berewicks', or 'subsidiary settlements' (Barnatt and Smith, 2004). For many of the villages in the Peak District, the Domesday Book in 1086 was the first official record of their presence, yet they may have existed for some time prior to it, though documentation either did not exist, was destroyed or lost (Barnatt and Smith, 2004).

3.2.3 Medieval Times and Beyond

In post-medieval times, coal mining was prolific in the east and west of the Peak District (Barnatt and Smith, 2004). Though digging into old sites occurred during the Roman period, such as at Minninglow, it was from the 18th century that many modern antiquarians began their search in earnest (Barnatt and Smith, 2004). The most famous of them being Thomas Bateman and Samuel Carrington in the 1840s and 1850s; though their work was done with "*unholy haste*" as described by Barnatt and Smith (2004, pg. 7), they set new standards for their time.

An imbalance was noted in what was excavated until the 20th century, with many ceremonial sites being targeted (Barnatt and Smith, 2004). In the latter half of the 20th century, excavations of settlements and fields became more frequent, and ages focused on prehistory to Roman time periods though all time periods were under ongoing surveys, with 5000 to 10,000 known sites being identified with new ones being found every year (Barnatt and Smith, 2004).

Due to the area being a National Park this has meant modern development has been limited; the Peak District can be defined as a palimpsest as there are traces of older features in with the new (Barnatt and Smith, 2004). Thusly, because of a lack of intensive farming, the gritstone regions – Dark Peak and South-West Peak - are remarkably well-preserved and due to the entire area being upland, intensive modern farming has been kept at bay, and features of antiquity are often still in use today (Barnatt and Smith, 2004).

3.3 Arbor Low, Gib Hill and the 'Avenue'

These two sites and ancient field boundary sit within a few hundred feet of each other. The three sites are of differing ages, changing importance in their histories, so they are often put together as one large complex of a henge, and older, long and round barrow, and the Avenue, thought to be a field boundary.

3.3.1 History and Geology of Arbor Low, Gib Hill and the 'Avenue'

It is situated on a false crest with extensive views to the north and northwest towards Monyash, Derbyshire and Lathkill Dale; when looking from Monyash towards Arbor Low it becomes a skyline feature, but as it is approached sight is lost until the northwest entrance is reached (Barnatt, 2019). Arbor Low has a high bank that prevents an individual from seeing out of the central plateau once inside except through the entrances, and the same for anyone standing beyond the bank from seeing in (Barnatt, 2019).

The southeast entrance is smaller than the northwest, and this leads to Gib Hill – a feature older than Arbor Low and a potential former focal point on the ridge before the latter was built; Barnatt (2019) described that attempting to move away from seeing Arbor Low as designed to control movement was hard to do, and appeared to have been in use for an extended time, evidenced by the construction of a barrow on to the henge bank. Barnatt (2019) also considered that there was a specific lineage potentially, or status, that was imposed on the people who congregated at Arbor Low.

McGuire and Smith (2008) produced a Conservation Plan for Arbor Low due to its national archaeological importance, which was recognised through scheduling. They described it as a "*visually striking site*" (*ibid*: pg. 9) and due to it now being situated near a major road in the Peak District National Park, it can attract a regular flow of tourists, among them those who value it as a modern resource of spirituality.

Prior to 2008, it was considered by English Heritage to be at 'medium risk' in 'declining condition', but as a result of restoration work it was 'improving' by 2008 (McGuire and Smith, 2008). The conservation plan used the concept of sustainability – which recognised the 'physical survivals' from the past and present create a record that contributes to understanding of past and present to plan for the future – and was intended to provide a long-term framework for management of the site and its setting; its first point was to assess its complex nature and significance, and determine any threat to its valued qualities, and its second point was to use this assessment for policy creation that enables significance to be sustained and attract support from those involved in policy making and implementation (McGuire and Smith, 2008). McGuire and Smith also acknowledged the need for inclusivity, that cultural and natural environments will be valued differently by people, so their plan had to identify management styles that met the sustainability needs whilst encouraging a range of engagements with the features and their locations.

Arbor Low is a Type II henge monument, defined as having two diagonally opposite entrances nearly north to south (Rogers, 2013) and Gib Hill is a barrow monument, and the long barrow was first built around 4000 BCE – 3000 BCE (McGuire and Smith, 2008). No element at the complex could be dated with exact certainty, and the building of it is chronologically uncertain in totality; however, it was theorised that it was cumulatively used for over 1000 years, circa 4000 BCE to 3000 BCE (Early/Mid Neolithic to Early Bronze Age) (McGuire and Smith, 2008). Initial creation of the near-circular embankment and ditch at Arbor Low was roughly dated to 3000-2000 BCE; analogous henge histories suggested that a timber circle may first have been constructed inside the earth embankments (Historic England, 2018dB) though no evidence of this has been found at Arbor Low.

The stone circle and other stone placements were dated to have been constructed within the embankments to the end of the Neolithic (2500 BCE – 2000 BCE) and therefore post-date the henge itself (McGuire and Smith, 2008). Following this, the round barrow on the south-east embankment was built in the Early Bronze Age (c. 2000 BCE) and part of that embankment was demolished to provide material; around the same time, a circular barrow was superimposed onto the Gib Hill long barrow, and that one to three smaller barrows were constructed close by (McGuire and Smith, 2008).

Roman pottery pieces were found, implying that people visited or passed through the area during the Romano-British period (70 CE to 410 CE). The course of a Roman road can be seen to the southwest, and the modern A515 Buxton to Derby road (two known Roman settlements) follows the same path. In the 7th century Anglo-Saxon barrows were constructed in the area: Benty Grange 1.5 km north-west, and a possible barrow on Middleton Moor 0.75 km to the north/north-west suggested that land was significant at this time (McGuire and Smith, 2008). It was potentially around this time the 'Avenue' may have been built; the ditch and linear bank abuts the southern edge of Arbor Low and curves around to south of Gib Hill and it is interpreted as an early property boundary (McGuire and Smith, 2008).

Until the 18th century, it is believed that Arbor Low was most likely to have been open heathland used for upland grazing, but the presence of the 'Avenue' suggested that some form of early land division occurred. The first academic-level mentions of Arbor Low occurred firstly in 1770 when the southeast barrow on Arbor Low was possibly excavated by W. Normanshaw and B. Thornhill, but work records are vague and could have meant Gib Hill, however there is evidence of unrecorded excavations (McGuire and Smith, 2008).

The stones, also termed orthostats, may have fallen at this time but it is not known if they were ever standing (Figure 3.3); an antiquarian named Pegge in 1785 recorded that a local man, aged 60, remembered a few hand been standing, and in 1789 a man called Pilkington noted a similar account (McGuire and Smith, 2008), but it does appear some orthostats were removed, likely to become gateposts. In 1782 Hayman Rooke, another antiquarian, was accompanied by James

Mander of Bakewell and dug four trenches into the south-eastern barrow, though they found little (McGuire and Smith, 2008). Writing in the 18th century, the antiquarian Reverend Pegge published in the journal *Archaeologia* about Arbor Low with a description and plans (Pegge, 1785); this was followed in 1789 by Pilkington's description and plan (McGuire and Smith, 2008).

Figure 3.3: An aerial shot of the orthostats at Arbor Low that may or may not have been standing in the past. (Image credit: Alex Nobajas/Helen Malbon).

In the 18th and early 19th centuries, the upland heath around Arbor Low and Gib Hill was enclosed, between 1785 and 1824 a few fragments of stone were removed from the circle, and by 1824 Arbor Low looked much like it does today (McGuire and Smith, 2008). In June of that same year, Samuel Mitchell and William Bateman dug further into Rooke's 1782 trench but found a single human tooth and animal bones (Bateman, 1861). In 1844, Thomas Bateman (son of the aforementioned William) dug into a small barrow 30 yards south-east of Arbor Low which had already been disturbed, but an iron fragment suggested either Romano-British or Anglo-

Saxon burial (Bateman, 1848; McGuire and Smith, 2008). Thomas Bateman then returned in 1845 to excavate the barrow on the southeast edge of the henge and discovered a limestone cist made of ten limestone slabs (Bateman, 1848). Bateman found coarse clay pottery inside (Bateman, 1848) and it was believed to have been within the cist dated to later Neolithic, which means the barrow is older than first thought, or the cist pre-dates the barrow (McGuire and Smith, 2008).

From the 1840s until the early 1900s, excavations took place with artefacts found by private collectors; in 1830s/40s the Primitive Methodists of Monyash held ‘camp meetings’ at Arbor Low, praying outside all day, in 1879 Sir John Lubbock delivered a lecture about Arbor Low at the site, in 1882 the Ancient Monuments Protection Act became law, and Arbor Low was in the first group of ‘archetypal monuments’, and given the number ‘*Derbyshire I*’. 10 small gritstone markers, engraved VR (*Victoria Regina*) marked the boundary of the scheduled area. 12th July 1884 the henge, stone circle and barrow were put under State Guardianship with Gib Hill (McGuire and Smith, 2008).

In 1901/1902 H. St George Gray excavated the henge and dug a number of trenches through the henge embankments, ditch and around the centre, and another at the foot of an orthostat; from this he made a survey of the site, numbered the orthostats and constructed a scale model for a museum display (McGuire and Smith, 2008).

In the 1980s, the Peak Park Joint Planning Board (PPJPB) records show access problems relating to payment for access over private land and the quality of the routes, parking and signage; a concessionary path was created in 1982 to avoid the farmyard and cowsheds, but it was then closed by the owner (McGuire and Smith, 2008). J. Barnatt created two hachured measured sketches of the barrow and henge, and the small south-easterly barrow as part of Peak District Barrow Survey in 1988 (McGuire and Smith, 2008).

In 1994 the scheduling was revised, Gib Hill was scheduled separately from Arbor Low, and the 'Avenue' was included instead, and in August a Condition Survey was completed by Trent & Peak Archaeological Trust for English Heritage. In 1995 the PPJPB (now Peak District National Park Authority, PDNPA) undertook the management of Arbor Low on a ten-year Local Management Agreement, and in 1998 and 2000 two geophysical surveys were done (McGuire and Smith, 2008).

Coming into the 21st century, in April 2003 a 25-year Licensed Access Agreement was drawn up between English Heritage and the landowners; in 2007 improvements were made around the sites, such as a visitor counter, interpretive signs, replaced styles, improvements to the slopes and surfaces, and erosion repairs on Arbor Low (McGuire and Smith, 2008).

3.3.2 The Local Landscape of Arbor Low and Gib Hill

Whilst the main focus is on the visualisation of the damage to the features, the reconstruction, and the resulting 3D models, the significance of the sites as a whole cannot be ignored. The setting of Arbor Low and Gib Hill is a part of the "*aesthetic, spiritual and intellectual appeal*," as described by McGuire and Smith, (2008, pg. 39).

As described, Arbor Low is set upon a false crest on Middleton Moor amongst pasture fields in the Derbyshire Peak District, also called the White Peak; it feels rather remote, with few trees aside from small plantations interspersed between the grazing fields (McGuire and Smith, 2008). The drystone walls to the north and north-west are on predominantly high limestone farmland in an intricate pattern, which is rather distinct around the nearby village of Monyash, approximately 3 km away in the same direction. To the north-east are the view to the East Moors, to the west and south-west are the limestone hills that stand above the Dove Valley into Staffordshire (McGuire and Smith, 2008). What trees are present disguise an industry in the area: former silica quarries at Blakemoor Pits are either grassed over or water-filled and provide habitats for wildlife; the only downside is the distant sound of traffic from the nearby A515 to the east-southeast (McGuire and Smith, 2008), itself was the route of a former Roman road.

The landscape contains several thousand years of history (Figure 3.4); to the south-east the great barrow of Minninglow can be viewed in winter from Gib Hill and at the summit of the barrow on Arbor Low. It is one of many barrows that lie on prominent hilltops, largely to the west and south-west (McGuire and Smith, 2008). Just to the north-west of Upper Oldhams Farm and Arbor Low a barrow existed, now ploughed away, but in 1848 Bateman unearthed the bodies of a child and a woman who wore an exquisite, beautiful and complex 420-piece bone and jet necklace; to the west of Gib Hill, is the A515, still partly following the course of a 2000-year-old Roman road, visible in the landscape to this day (McGuire and Smith, 2008). One of the rarest Anglo-Saxon finds was discovered only 1.5 km to the north-west at the 7th century Benty Grange: an Anglo-Saxon helmet – one of only four found in the country – was recovered by Bateman in the 19th century, clearly high-status and decorated with a silver Christian cross and a pagan symbol of a wild boar (McGuire and Smith, 2008).

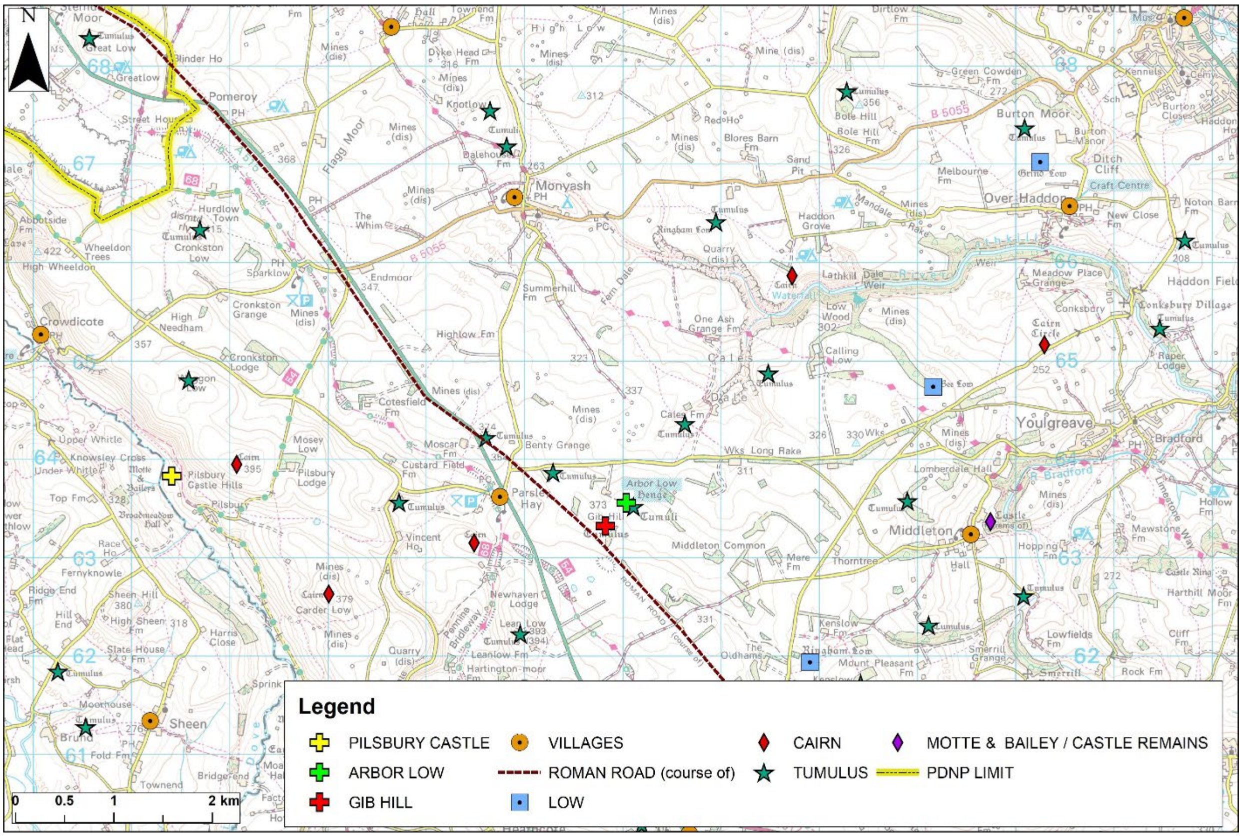


Figure 3.4: A localised map displaying the other features in the area around Arbor Low, Gib Hill and Pilsbury Castle inside the Peak District National Park (PDNP) (adapted from Edina Digimap, 2018).

Ecologically, the Arbor Low and Gib Hill fields have decreased in value over the last two decades; in the mid-1980s they were considered ‘key ecological areas’, and then improved after this but when it was re-surveyed by the PDNPA in 2004 there was no ecological interest aside from the banks of the henge (McGuire and Smith, 2008).

3.3.3 Location and Construction: Arbor Low

Both Arbor Low and Gib Hill sit at 370 m Ordnance Datum (OD) on uplands of the Derbyshire limestone plateau (McGuire and Smith, 2008). Barnatt and Collis (1996) analysed the position on the ridge they occupy as being an important watershed position and of significance in relation to how the landscape appeared to have been occupied by contemporary peoples. Arbor Low is described as being on a ‘false crest’ (McGuire and Smith, 2008; Rogers, 2013). North and north-west are the Monyash Basin and Lathkill Dale, to the south-east the land steadily rises, limiting views from this direction; however, if an individual did stand atop the embankments Minninglow can be seen to the southeast, which is a ‘great barrow’ from the Neolithic. Immediately west and south-west of Gib Hill the land drops steeply to the A515 road before rising into hills east of the Dove Valley (McGuire and Smith, 2008).

Figure 3.5: An aerial photograph of Arbor Low from February 2020, showing the barrow in the bottom left of the image (Image credit: Dr Alex Nobajas and Helen Malbon).

Arbor Low is a Type II henge (Rogers, 2013), with two entrances diametrically opposing each other north to south (Figure 3.5). The embankments, when first constructed, were 3 m high and built using white limestone, chert and rubble but is grassed over; today the banks are about 2.1 m high on average with an external diameter of 75 m x 79 m, and varies 8 m – to 10 m in width (Burl, 1979; McGuire and Smith, 2008). It is from Gray's early 20th century excavations that we know of the structure of the banks; on the west side of the northern entrance the bank was constructed with limestone rubble, thin layers of chert and soil derived from the ditch, then east of the same entrance the banks were built from limestone boulders, the maximum length reached 4 feet (1.22 m) (Gray, 1904; McGuire and Smith, 2008). From the same excavations, the inner ditch was determined to be less regular than the embankments; the width varied from 7 – 9 m on the western side to 9 – 12 m on the east, and Gray went on to find that the ditch was formed from steep rock-cut sides and had an uneven base so the original depth oscillated between 2 and 3 metres (Gray, 1903, 1904; McGuire and Smith, 2008). To the immediate east of the northern causeway/entrance, Gray believed he had found evidence of rock-cut steps leading down into the base (Gray, 1903, 1904; McGuire and Smith, 2008), and the entrances also vary in width, the north is 9 m wide, and the south entrance is only 6 m wide.

From analogy with other henges, there may have been paired stones at the entrances but no excavations as of 2008 had taken place to determine this potential (McGuire and Smith, 2008). There is a limestone stump within the southern entrance, and a recumbent stone lying across the entrance yet these individual pieces do not match to imply it broke and fell, however there is a 2 m diameter pit at the north entrance that indicates that perhaps both entrances had a 'portal stone' (McGuire and Smith, 2008). Within the henge, there are approximately 50 large limestone orthostats that form the ruined stone circle, and another two have fallen into the ditch; it is believed that there were only about 40 stones due to evidence showing that some fragments came from another orthostat that is now broken (McGuire and Smith, 2008). There has been debate about whether these now recumbent orthostats ever stood, however Barnatt

(1990) notes seven stumps remain in situ, which confirmed they did once stand upright, as was mentioned by Pegge in 1785 and Pilkington in 1789. Barnatt (2019) went on to say that the original circle had a circumference of c. 42 x 37 m with each orthostat equally spaced around it.

There are indications that the tallest stone stood near the southern entrance, with four orthostats standing at 2.6 to 2.9 m high; another two at the north entrance were tall, but the majority were between 1.6 and 2.1 m tall, and through calculation from a vantage point in the centre only the largest stones would have protruded over the embankments, and none would have been visible outside of the hedge except through the entrances due it being positioned on a crest (Barnatt, 1990; McGuire and Smith, 2008). Gray (1904) described the orthostats as having varying thickness, irregular forms, were decayed and fractured; some were pillar-like whilst others were wide slabs, and he believed they had been brought from a distance as they did not match the limestone in the ditch, but no experiments have been undertaken to establish this. Therefore, they may be from the de-turfed bedrock along the course of the ditch (McGuire and Smith, 2008).

The cove stones at the centre of the plateau were amongst the tallest at Arbor Low, thought to have made a rectangle 3 – 4 m across of 6 orthostats; the north and south entrance cove stones were about 2.9 – 3 m high and Barnatt (1990) theorised they would have blocked the view of the interior of the cove from outside the henge due to their position. The other orthostats, smaller, are in pieces in the south-west side of the cove, and the north-east side is hard to reconstruct (McGuire and Smith, 2008). On the eastern edge, during an excavation Gray unburied an extended skeleton, though incomplete, of a male, unknown date; the skull was about 37 cm from the surface, was partially crushed and weathered in forty to fifty pieces, and the lower jaw was not present (Gray, 1904).

The barrow in the south-east henge bank is a later addition. It has a diameter of approximately 21 m with a modern-day height of 2.3 m, and the henge to the north and south-west of the barrow have been greatly reduced, likely to construct the barrow (McGuire and Smith, 2008). The craters present on its summit suggest there has been excavation here several times by Rooke in 1782, and Mitchell and Bateman in 1824 (McGuire and Smith, 2008), and this spoil was thrown into the ditch and around the sides. Thomas Bateman, in 1845, dug deeper into the southern rim and unearthed the cist containing pottery closely tied to Peterborough Ware, which gave a date of the Later Neolithic (Barnatt and Collis, 1996) and raised complex questions of chronology due to the positioning on the cist when found and the construction of the henge and barrow (Barnatt, 1990; McGuire and Smith, 2008), and the age of the pottery (Rogers, 2013). Peterborough Ware pottery has been frequently found at sites associated with death and the afterlife, with burials in the English midlands and the Peak District (Pryor, 2004), and Rogers (2013) proffered Arbor Low likely was a ceremonial site of that nature.

There are traces of excavations pre-20th century, as seven trenches can be seen on the eastern bank that predate Gray's 1901-1902 work; these may be from Bateman and Isaacson in the mid-19th century but it cannot be confirmed (McGuire and Smith, 2008); the same is thought of two areas of earlier digging near the central cove. Arbor Low and Gib Hill were both targets for early excavators; the barrow on the henge is cratered at the summit, and the henge ditch has clearly been cut into many times (Barnatt, 1990; McGuire and Smith, 2008), and as they were not properly recorded, it is hard to determine if they were from Normanshaw and Thornhill in the late 18th to early 19th centuries. Rooke in 1782 spent five days on the barrow dig – considered an inordinate amount of time for barrow digging in the 1780s (Marsden, 1999) – and he cleared away the centre of the mound (Rooke, cited in Ward, 1908). In 1824, Mitchell and Bateman also dug into barrow mound and Rooke's trench but found only a human tooth and animal bones (Bateman, 1848; Ward, 1908).

The only truly successful excavation of the 19th century was Thomas Bateman and Reverend Stephen Isaacson in 1844/45; they worked form the south side of the barrow to the centre and found inside the cist with Peterborough Ware-type pottery, a flint, human bones (burnt), a bone pin, an iron pyrites piece and an ornamented rim sherd of unknown types (Barnatt, 1990).

Harold St. George Gray's excavations in August 1901 and May/June 1902 was the last to take place in the last century it had been organised by the Anthropological Section of the British Association (McGuire and Smith, 2008). Gray (*1872 - 1963*) had been an assistant to General Pitt Rivers, became chief assistant in 1899 at the Pitt Rivers Museum in Oxford; when he excavated Arbor Low he was curator at the Taunton Museum (McGuire and Smith, 2008). His team produced several plans and surveys:

- Measured survey of the henge, the circle and the northern part of the 'Avenue', with contours and orthostats placings (Figure 3.6).
- Numbering system devised for the orthostats (Figure 3.6)**.**
- Several excavations in the henge embankments and the ditch, around the central cove and the northern end of the 'Avenue'
- Created a scale model of Arbor Low from a block of mahogany and soapstone

Figure 3.6: Adapted from Gray (1904), a detailed hand-drawn plan of Arbor Low during H St. George Gray's 1901/1902 excavations of Arbor Low and the 'Avenue'. Red highlights the extents of the trenches, the Roman numerals is the numbering system Gray devised, brown is the area of excavation, and the orange, greens and blue highlights the 'Avenue', plateau, ditches (fosse), banks (vallum), and the barrow.

Gray also excavated on either side of the northwest entrance of the henge, and demonstrated the structural differences there, as previously described. Six trenches were dug into the ditch at various points, two were either side of the northwest causeway entrance and the at the western ditch terminal that abuts the south-southeast causeway (McGuire and Smith, 2008). There were two ditches across the western side and one on the eastern; from these it was determined that when the ditch was first built, it was between 2 to 3 m deep, with steep side and an uneven base (Gray, 1904; Barnatt, 1990; McGuire and Smith, 2008). It was at the northwest ditch that Gray interpreted the presence of limestone steps; many relics were discovered in the ditch including arrowheads, red deer horn, an ox leg bone, and a scraper (McGuire and Smith, 2008). The ditch at the southern causeway yielded many ox teeth on the limestone base of the ditch (McGuire and Smith, 2008). The 'central cove', however yielded a skeleton on the east side, male, extended with the head to the south-southeast; it was weathered and in a shallow grave, barely 0.37 m from the surface (Gray, 1904).

Gray also excavated the 'Avenue' to determine whether the ditch continued beneath Arbor Low and potentially prove its age (Gray, 1904). The trench was 2.1 m wide and 7.6 m south of the henge, and he placed a second trench 2.5 m wide across where it joined the henge bank (McGuire and Smith, 2008). He discovered that it comprised a rock-cut ditch, 0.9 m overall and nearly 2.4 m wide at the top, meaning it was deeper and wider than it appears today (McGuire and Smith, 2008). Gray (1904, pg. 64) describes it as "*only 1.5 foot above the level of the surrounding field*" suggesting it has been severely reduced; the bank, where it was excavated, was circa 3.7 m wide (McGuire and Smith, 2008). Though Gray believed the 'Avenue' and the flint relics he found proved it and the henge were contemporary, Barnatt (1990) felt that the flint was residual and cannot date the 'Avenue', but instead believed that it is an early land boundary marker.

English Heritage carried out a geophysical survey in 1998 with a magnetometer and resistivity meter of the interior and entrances, but very little data was gathered from the magnetometry which found already known features and evidence of prior fencing (McGuire and Smith, 2008) and the resistivity survey of the interior documented the proximity of the bedrock from the surface (Martin, 2001). The topographical survey was carried out in November 2007 by English Heritage in which the tops and bottoms of man-made structures were recorded to demonstrate their extents and stratigraphic relationships; all features had previously been identified by Barnatt (1991b, 1993).

According to McGuire and Smith (2008), in the later Neolithic, henges and large stone circles replaced barrows and chambered tombs to reaffirm community behaviour and identity of the people; they have no precise dates but most henges dated to around the 3rd millennium BCE, and were continually built throughout the Later Neolithic in areas that appear to have been able to support a relatively large prehistoric population (McGuire and Smith, 2008). Arbor Low is one of two major henges in the Peak District area, the other being the Bull Ring near Dove Holes, Derbyshire, which will be discussed later in this chapter.

Arbor Low has architectural elements that many other henges across the British Isles have, suggesting, as Barnatt (1990) has written, that the elements were part of a repertoire of forms built from the Orkney Isles to Cornwall. In a few cases, stone circles were constructed inside henges, normally using tall, evenly spaced orthostats, but timber circles were also built which are comparatively harder to detect; future work at Arbor Low may indicate a presence of an earlier timber circle (McGuire and Smith, 2008). Central coves have been observed at Stonehenge, Avebury, and Mount Pleasant in south-west England; there is potential evidence for portal stones at Arbor Low too, flanking the entrances, which has also been seen in southern Scotland, Cumbria and south-west England (McGuire and Smith, 2008).

In the last decade, more complexity has been identified at henge monuments through research projects, such as the Stonehenge Riverside Project (Heath *et al.,* 2013). The Arbor Low Environs Project (ALEP) was created to reconsider the henge and its surrounds; particularly through the phenomological approach, the concept discussed in Chapter 2, about the siting of monuments in landscapes rich in ritual resources (Heath *et al.,* 2013).

3.3.4 Location and Construction: Gib Hill

Today's Gib Hill was built in two phases: the upper level is a large, high, steep-sided round barrow, also called a bowl barrow of which there are several in the Peak District. It is thought to be from the Early Bronze Age, but is superimposed on the southwest end of an older long barrow, possibly from the Early Neolithic (Figure 3.7) (McGuire and Smith, 2008). The older long barrow is circa 46 x 28 m, but its height is given as 1 m by Barnatt (1990) and 2 m by Historic England (2022b).

McGuire and Smith (2008) believed this is due to a difference in base measurement point. Excavations in the 19th century suggested that a portion of the structure was built from earth and not stones (McGuire and Smith, 2008). The superimposed barrow stands 2.5 to 3 m above the 1 – 2 m high long barrow and is around 24 x 27 m in diameter. An excavation in 1848 revealed the limestone cist which most likely had been set on the summit of the older long barrow before the construction of the round barrow (McGuire and Smith, 2008).

A narrow berm, a ledge of level space between a bank and a ditch or scarp, surrounds the mound and beyond it are several shallow pits that may be quarry ditches that provided material for construction of the barrows; though Historic England (2022b) suggested on their scheduling description that they are prehistoric, they are disturbed by later quarries to the east and west. Barnatt (1989a) did not agree and suggested the whole group of pits could be a series of later quarries.

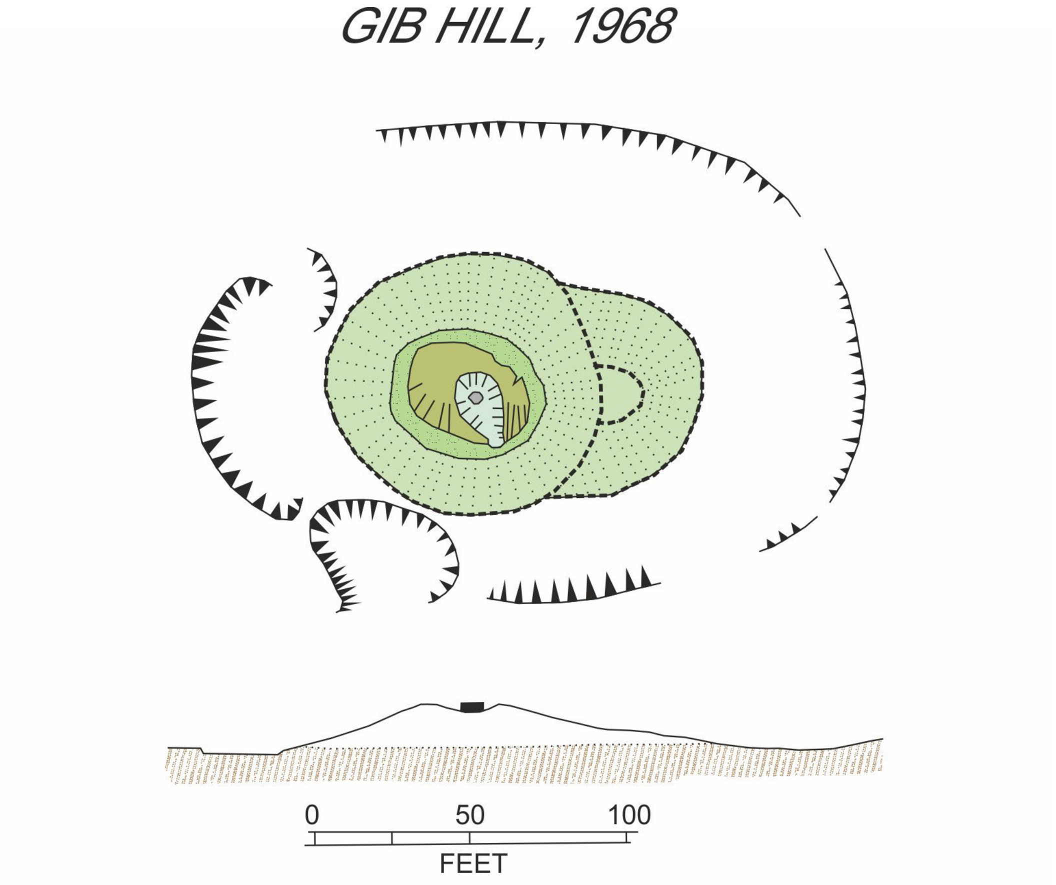


Figure 3.7: Gib Hill survey, adapted from Radley (1968).

Like its neighbour, Gib Hill has been a popular target for excavation though few records survive of the earliest attempts (McGuire and Smith, 2008). The late 18th century landowner, Mr Normanshaw is said to have dug into either Gib Hill or Arbor Low for stone and recovered a human skull (Ward, 1908); when the antiquarian Pegge (1785) published his work he also recorded that the mound had a hollow in the middle in a basin shape. In the early 19th century, Mr Bache Thornhill of Stanton dug into Gib Hill, or Arbor Low, and found human hand bones and Roman coins (Ward, 1908) but he denied ever digging in Gib Hill. Barnatt (1991) suggested that there is some confusion between the stories of Normanshaw and Thornhill.

As with Arbor Low, the first recorded excavation was that of William Bateman and Samuel Mitchell across two days in June of 1824 (McGuire and Smith, 2008). They dug from the southeast side to the centre, and it was recorded that the uppermost section was composed of loose stones and soil, followed by a thin layer of ‘tuft stone’ then a final yard and a half of stones and earth with a thin layer of ‘tuft stone’; below all that is red-brown clay, described as stiff, laid on the natural soil a yard and half thick, 3 to 4 yards wide and disposed in layers are burnt bones and charcoal in its circumference (Ward, 1908). Several pieces of flint were found, a 2.5-inch-long arrowhead, an axe head, a piece of a Roman broach (now lost), and a separate iron piece (Bateman, 1848; Ward, 1908).

The next excavation took place in 1848, by Thomas Bateman; he dug from the southeast to the centre and opened a wide gash in the mound where he found animal bones, an arrowhead, a rim of an urn amongst other items (Bateman, 1861). After three days, they sank the trench to the base and exposed four separate mounds of clay on the old ground surface that contained wood, charcoal and damaged oxen bones (Bateman, 1861).

Bateman then created a tunnel from the west into the barrow, some 2.5 to 3.5 m further in order to find a burial; when he believed the tunnel was unsafe, he had his workers leave and remove timber supports, which lead to the aforementioned limestone cist falling into the tunnel from above (McGuire and Smith, 2008). The cist was formed by four limestone slabs, covered by a fifth that measured around 4 feet square and 10 inches thick (Bateman, 1861), and within were a food vessel and cremated remains. Bateman removed the cist to his home, Lomberdale Hall in Middleton-by-Youlgreave, but in 1938 it was replaced on the barrow and the capstone is visible to this day; the excavations can also still be detected today due a slight slump in the backfill (McGuire and Smith, 2008).

Like at Arbor Low a geophysical survey was completed in 1998 and 2000; a resistivity survey was employed in the limited area between the boundary stones and temporary fence. The report concluded that there was no way to determine if the variations detected in resistivity were part of any pattern (Martin, 2001). The topographical survey in 2007 recorded the tops and bottoms of the features and their stratigraphic relationships (McGuire and Smith, 2008).

3.3.5 Location and Construction: The 'Avenue'

The feature known as the 'Avenue' is a linear ditch and bank, low but broad that is traceable from a point on the south-west bank of the henge that runs in that direction for about 150 m, reappears after a gap of 70 m turning to the west and curving to south of Gib Hill where it continues into Gibhill Plantation; here it forms a high lynchet but has been disturbed by some quarrying (McGuire and Smith, 2008). The topographical survey of 2007 shows the 'Avenue' continues into improved pasture west of the plantation then peters out, and a survey taken as part of McGuire and Smith (2008)'s plan showed that this curving field boundary is not found of an associated bank or ditch, but the fields beyond this plantation have undergone agricultural improvement.

The low bank is 2 to 3 m wide and no more than 1 m high (Historic England, 2022a). The ditch is on the east/south side of the low bank and though the document gives a width of 0.6 m, it is believed by McGuire and Smith (2008) to be too narrow, as by the drystone wall to the south where it is cut off the ditch is near 2.5 m wide. Gray (1903, 1904) dug just 2m of the bank and 6 m under the ditch to find a substantial feature; before silting it was 2.4 m wide at the top and cut into the limestone bedrock to an average depth of 0.9 m, with its maximum extent being 1.2 m, and the width of the low bank he excavated was circa 3.7 m. It is difficult to find and provide useful context for the 'Avenue' due to conjecture surrounding its original use and date of construction; it is considered to be an early property boundary that postdates the henge, potentially Romano-British, Anglo Saxon or even later, but it could also be prehistoric (McGuire and Smith, 2008). If it is of the Romano-British period, then this lined up with the theorised preferment of limestone by people in the Peak District at that time (Bevan, 2005).

Though there are Anglian barrows in the Peak District, there is little known of immediate post-Roman history and activity, but the barrows – and reuse of older burials – suggests that there were settlements from the late 7th century onwards on the limestone plateaus (Barnatt and Collis, 1996).

3.3.6 Preservation of Arbor Low, Gib Hill and the 'Avenue'

Since 1884, the henge only was under the guardianship of the Secretary of State (currently Culture, Media and Sport) but is managed on their behalf by English Heritage (McGuire and Smith, 2008). The land around Arbor Low is tenured and it is owned by the Trustees of the Middleton Estate but grazed by farmers of Monyash, and the agreement allows for sheep to graze between specified dates with a few conditions that need to be met including right of public access, maintaining of gates and fences, control of weeds and indemnification of English Heritage as is appropriate (McGuire and Smith, 2008).

In February of 1995, the *Historic Buildings and Monuments Commission,* now English Heritage, entered a 10-year Local Management Agreement (LMA) with the PPJPB, now the PDNPA; this Agreement gives PDNPA the responsibility of everyday management of Arbor Low however nothing was mentioned of the 'Avenue' (McGuire and Smith, 2008); as of 2009 it had expired and was awaiting the replacement – a Maintained Property Agreement (MPA).

Essentially, the PDNPA has to "*protect, conserve and where possible enhance the 'archaeological, historical and natural history resource' represented by the Arbor Low and Gib Hill monuments…to promote awareness and understanding of the monuments*" (McGuire and Smith, 2008, pg. 42). The PDNPA have several tasks to keep to including:

- Use the 1994 Condition Survey to bring the land to base level
- Regular inspections for littering, damage reporting and site health
- Maintain grassed area
- Control weeds and saplings with appropriate methods
- Control burrowing animals

- Create a programme for appropriate on and off site media
- Maintain the marker posts
- Prevent camping and fires as best as possible, advise English Heritage of campers or unauthorised visitors, and take reasonable steps to remove them
- Prepare proposals for a programme and specification after contacting the relevant landowner to improve car-parking, access and payment arrangements.

There was a principal change in a draft version of the revised LMA and that is the area covered by this Agreement encompasses the entire field in which Arbor Low is situated and not solely the henge, barrow and circle (McGuire and Smith, 2008).

Gib Hill is also tenured and owned again by a farmer of Monyash; and like Arbor Low was in the guardianship of the Secretary of State since the 19th century and managed on their behalf by English Heritage (McGuire and Smith, 2008); the PDNPA entered an agreement to maintain Gib Hill exactly as the do Arbor Low in the ten year LMA in 1995 and the aforementioned tasks are also appointed to Gib Hill.

An agreement was entered into with the farmer and English Heritage in 1998; it was made under Section 17 of the Ancient Monuments and Archaeological Areas Act 1979 and ran for five years to 2003, and as of 2008 a decision to renew it was yet to be made (McGuire and Smith, 2008) Under the Agreement, the farmer was obliged to:

- Maintain permanent grass cover
- Control weeds and burrowing animals
- Control stock levels to prevent grass cover reduction if the site is grazed
- Reseed eroded areas
- Control saplings and shrubs
- Obtain appropriate permission for any works which may break the ground
- Ensure stock-proof fencing is well maintained

A fence was erected around Gib Hill which is still in place today, though cattle still occasionally get through, including some time in 2019 according to the PDNPA, which impacts the monument. Some repair work was needed at Gib Hill and in 2002 the PDNPA and EH discussed the need to mend the erosion scars and the time needed for repairs to establish; by 2003 the eroded sections were grassed over but more work was needed (McGuire and Smith, 2008).

The 'Avenue' is not under any guardianship unlike Arbor Low and Gib Hill are as the entire visible length of it is scheduled with Arbor Low and these sections are in land covered by four differing ownerships and/or tenancies:

1) The northern most section is in Arbor Low field owned by the Trustees of the Middleton Estate and leased to EH
2) Directly south of the Arbor Low field a short section lies on land owned by Trustees of Middleton Estate but managed by a farmer in Middleton-by-Youlgreave (as of 2008)
3) More sections run alongside the north-east boundary of Gibhill Plantation, and the field is owned by a farmer in Mayfield but is managed by another farmer in Hartington; many rather broken sections here are not included in the scheduling
4) It then runs through the plantation, that had changed ownership by 2008
5) The farthest west section lies inside another field owned and managed by two different farmers

Sections 1 and 2 are under limited discussion with the tenants and/or landowners about management and conservation, but the rest of the 'Avenue' section 3 through 5 have none, despite the fact scheduling gives all sections legal protection from disturbance; in fact, in the cases of Sections 2-5 the landowners/managers were entirely unaware of the scheduled monument on their land (McGuire and Smith, 2008).

Section 1 was not originally protected in the LMA, but under the then drafting of the MPA, it would be. Section 2 was ploughed every three to five years by the former tenant, however in 2009 the new tenant affirmed it was no longer ploughed; therefore, the field in Calling Low Farm was in better condition than Arbor Low field (McGuire and Smith, 2008). Regardless, whilst the earthwork is still visible in Section 2, it is much smoother.

Section 3 of the ‘Avenue’ is at the edge of a cattle-grazed field, Section 4 is within the plantation that is also grazed by cattle, and Section 5 is used for silage, little grazing and was ploughed in the past, however the landowner does not intend to plough in the foreseeable future as of 2008/9, and was willing to work with the PDNPA / EH to manage this section of the ‘Avenue’ as the landowner was not aware of the feature until 2008/9 (McGuire and Smith, 2008). Implications of the highly detailed topographical survey was still being assessed at the time of McGuire and Smith (2008)’s conservation plan.

3.3.7 Monument Condition: Arbor Low

Arbor Low was assessed in 2007 by EH and deemed to be at ‘medium risk’ and in ‘declining’ condition with the main erosional threat from livestock; repairs carried out by EH in later 2007 revised the condition to ‘improving’ condition (McGuire and Smith, 2008).

Between 1994 and 2007, several surveys took place to determine the condition of Arbor Low together with Gib Hill. In 1994, Trent & Peak Archaeological Trust carried out a condition survey to record extent of erosion (Guilbert 1994a). Erosion was focused on the barrow and the eastern henge crest; the barrow erosion derived from older archaeological trenches and then exacerbated by visitors using them as pathways and as a place to congregate (Guilbert, 1994a; McGuire and Smith, 2008). The crest of the eastern bank had bare patches that created a worn strip and is more prevalent than on the western edge, which has a marked footpath along its crest though not as serious, but a path followed up the bank from the direction of a former stile to the northwest (Guilbert, 1994a; McGuire and Smith, 2008).

The ditches in 1994 were not in too bad a condition; there was some erosion on the inner scarp opposing the barrow, likely because people used it to walk up to the barrow, and a small erosion patch occurred on the west of the causeway; in the eastern ditch, at the base, is a modern fire-pit, 1 x 0.5 m (Guilbert, 1994a; McGuire and Smith, 2008). In the central cove, erosion was confined to two small areas at the inner end of the northern causeway, two thin strips between stones near the causeways and adjacent to a large cove stone (McGuire and Smith, 2008). Guilbert (1994a) noted that some turf had been cut away on the northern side of an eastern orthostat, which he replaced in hopes of re-establishment; he also noted grassed-over hollows adjacent to other orthostats (Guilbert, 1994a; McGuire and Smith, 2008).

From 1995 to 2006, erosion presented increasing issues at the site, largely due to cattle, but visitors also impacted in particular areas (McGuire and Smith, 2008). By 1999, cattle were reported again, and also damaged by quad bikes – children from a local farm – thereby resulting in discussions between EH and PDNPA for a condition survey prior to repairs (McGuire and Smith, 2008). In 2001, much more noticeable erosion was reported by the PDNPA Ranger Service; in April 2002, PDNPA reported to EH that series of erosional patches, likely from sheep scrapes, developed in Arbor Low, and there was continuing cattle-derived erosion on the inner face of the henge bank (McGuire and Smith, 2008). The path that led from a former stile to the north-west and went right up and over the bank had become more ‘marked’ since the interpretive sign had been removed (McGuire and Smith, 2008).

In September 2003, EH entered into a 20-year lease of the field, agreed with the owner, Trustees of the Middleton Estate, which enabled EH to exert more control; they drew up a grazing agreement with the farmer, who also owned the adjacent Gib Hill field to reduce agricultural impact (McGuire and Smith, 2008). However, by April 2004 the erosion had worsened; a large area of 3 x 2m had developed on the north-west facing side of the barrow and on the henge bank below; the Park Ranger Service noted that a substantial amount of material was slipping, and that visitors were moving small pieces of rock about the area (McGuire and Smith, 2008).

By December 2004, a draft specification was drawn up for recording, mitigation and monitoring works at Arbor Low and Gib Hill, which identified the erosion around the barrow and the ditch adjacent as high priority and was the most serious damage (PDNPA, cited in McGuire and Smith, 2008) Other significant areas were on the inner face of the henge bank, and the desire path over the western bank. The paths along the crests were deemed stable, and with only a few exceptions, evaluated as minor priority (McGuire and Smith, *ibid.*).

In 2007 a crushed limestone path was created to guide people the entrance rather than the desire path over the bank, and around the newly installed pedestrian gates to prevent erosion there (McGuire and Smith, 2008). Repair works were carried out in October and November of that year by Derwent Treescapes for EH, which followed the specifications outlined by the PDNPA; all high priority areas in Arbor Low were repaired, and followed up with the topographical survey of 2007 to provide a baseline for future change (McGuire and Smith, 2008). As of 2008, as reported by McGuire and Smith (2008) Arbor Low appears to be in good condition, though some areas are still bare on the inner summit of the northern bank, the steep path down the northern side of the barrow, and some portions of the henge top paths.

There have often been visitors that come to Arbor Low around or on the Solstice; in the late 1980s and early 1990s there had been concern about campers, though the area was not visibly damaged, and Ranger Service reports indicate the site has been left in good condition and undisturbed (McGuire and Smith, 2008). Offerings are left, mostly on or near the cove stones, and some ephemeral artwork made from flour have brief impacts with no lasting effect (McGuire and Smith, 2008). Regardless, there are small scale issues that do arise at the site, such as a small fire pit, re-turfed in 2007 but re-dug in 2008 closer to the henge itself, removal or loosening turf around the orthostats, using eroded stones to create patterns and clusters of stones placed on or against the orthostats; EH had intentions to erect a sign on a gate asking visitors to respect the monument as of 2008 (McGuire and Smith, 2008). In communication with J. Barnatt, McGuire and Smith (2008) reported that he has noted an increase in offerings left in the last 30 years, usually of coins, flowers and crystals; as a result, he believes there is an accumulation of buried objects now at Arbor Low.

3.3.8 Monument Condition: Gib Hill

As of 2007, Gib Hill was considered to be at 'medium' risk and 'declining' with the principal threat being livestock, and by January of 2008, an EH representative revised the status to 'medium' risk but 'improving' (McGuire and Smith, 2008). Guilbert (1994b) with Trent and Peak Archaeological Trust in 1994 as he did with Arbor Low. The report identified four localised points of erosion on the southern side of the mound (Guilbert, 1994b; McGuire and Smith, 2008). The northernmost of these patches is some way up the flank, measured 2 x 2 m and exposed stratified layers of dolomitised limestone and clay, some burnt so steel nails were inserted to aid in a more comprehensive recording before repairs (Guilbert, 1994b; McGuire and Smith, 2008). The second patch was at the south-southwest foot of the barrow where a steep-sided, flat hole at 1 m in diameter; it was where a Victorian boundary marker was situated but had been moved (later restored) (Guilbert, 1994b). The third patch was developed around an EH information board which was leaning against another boundary marker 12 m to the east of the site (Guilbert, 1994b; McGuire and Smith, 2008). The fourth section was close to the north-east corner of a sizeable limestone slab on the south of the mound; overall Guilbert (1994b) reported there was little in the way of active erosion and lush turf cover at Gib Hill, but he noticed that there were many divots that broke the ground, particularly on the steeper sides, which he associated with cattle. Indeed, cattle had recently got into Gib Hill in late 2019, according to the PDNPA.

Near 18 months following the survey by Trent and Peak Archaeological Trust the condition deteriorated; in spring of 1996, a tractor was repeatedly driven up and down the barrow from the north side, and this damage was exacerbated by young cattle congregating on the summit (McGuire and Smith, 2008). Following that, the then new landowner ploughed between the monument and the plantation to the south and unwittingly ploughed the scheduled area and over the southern ditch to the base of the barrow itself (McGuire and Smith, 2008). At this time one of the Victorian markers were removed, but later restored, and in 1997, following remedial discussions with the landowner a temporary electric fence to prevent cattle entering and allow for the erosion to heal; however, for inexplicable reasons, the fence post was repeatedly damaged, thus the fence was removed (McGuire and Smith, 2008).

In 1997, the PDNPA reported that the barrow was suffering from severe erosion and proposed a survey to map the damage, alongside archaeological recording and detailed plans of the sections of exposed stone body of the barrow beneath (McGuire and Smith, 2008). In December of the same year, a 5-year Management Agreement was agreed and a fence with two stiles and a gate was constructed around Gib Hill, with a limited number of sheep allowed to graze on the barrow to keep scrub from growing (McGuire and Smith, 2008). Despite this, between 1998 and 2001 reports indicated cattle still gained access.

In May 2000, a ranger noted the erosion scar on the north-west side was not healing; in April 2002, the monument was recovering but areas still needed repairs with topsoil and turf, followed by pinning after recording and would then need time to re-establish (McGuire and Smith, 2008). By 2004, the northwest scar was starting to heal, but bare ground was visible due to people travelling up and down the side from the stile; the PDNPA produced a draft specifying recording, mitigation and monitoring works for Arbor Low and Gib Hill, it identified the north-west scar, as well as eroded areas on the west, south-west and south facing areas (McGuire and Smith, 2008).

In 2007, Derwent Treescapes Ltd., on behalf of EH, reset the boundary marker and though there was no specification for reinstatement of grass around it, vegetation is re-establishing itself (McGuire and Smith, 2008); the northwest scar had no major repairs carried out, but an area of it appeared to have been re-turfed; the areas around the stiles and gate become incredibly muddy in wet weather, causing erosion at each location, and finally there are desire lines still present, the most predominant route being from the northwest stile over the north-western slope (McGuire and Smith, 2008).

3.3.9 Monument Condition: The 'Avenue'

In 1994 there was no specific condition survey dedicated to the 'Avenue', however Guilbert (1994a) noted that the earthwork did not suffer much under grass, and that this seemed to apply to nearly all sections aforementioned. Guilbert (1994a) did also acknowledge that a narrow band in the field near to Gib Hill had suffered much from cattle using it as a track, which still was in use as such in 2008, that it was not eroding as it had barely survived.

Section 2 of the 'Avenue' is situated in the field south of Arbor Low; it was clear from 1996-2008, that this field had been improved in the recent past, and in 1996 the former tenant told the PDNPA that it was ploughed for re-seeding every three to five years but the current – as of 2008 – confirmed it is no longer ploughed (McGuire and Smith, 2008); as a result, the earthwork is still visible but much smoother than what survives in the field with Arbor Low.

Section 4 of the 'Avenue', despite what Guilbert (1994a) feared, had survived somewhat, but the topographical survey in 2007 did highlight that cattle still got into Gib Hill plantation and took the same course across the earthwork (McGuire and Smith, 2008). Section 5 in the 2007 EH survey showed that despite ploughing five years earlier (confirmed by the landowner) it still exists to nearly halfway across the field (McGuire and Smith, 2008).

In 2013, Heath *et al.,* (2013) determined that the Avenue extended 100 m west beyond the terminus point that had been defined in years previous. As part of the ALEP, the use of magnetrometry and resistivity found it continued beyond the former terminus but did not extended into the neighbouring field south of Gib Hill, but Heath *et al.,* (2013) suggested that it “seemed strange” (pg. 19) that it respects boundaries of a later field wall and does continue past it.

3.3.10 Land Use

Land use will have an impact on the erosion and damage at these sites; different groups of people interact with heritage sites, and this with agricultural activity across time will have an impact on earthwork heritage monuments. The extent of the fields is considered to be of archaeological interest due to the findings already discovered, but both are currently grazed (McGuire and Smith, 2008). According to PDNPA records, the Arbor Low field has not been ploughed since the mid-1970s and no research has been conducted into ploughing prior to this date; 20th century aerial photography has also revealed that the fields have been grazed since the early 1900s and likely for decades before that which will eventually have an erosive impact on the site over time (McGuire and Smith, 2008).

Gib Hill’s southern section has been ploughed since 1996, yet the PDNPA record from mid-1970s until 1996 has no record of ploughing, and since 1996 there has not been ploughed subsequently; it can also be assumed this field was also grazed for decades (McGuire and Smith, 2008). The landowner for the section of the field that was quarried agreed to contact the PDNPA should he change any of his activities in that area to determine what implications would arise from the change (McGuire and Smith, 2008).

The Peak District has around 13.25 million visitors every year (PDNPA, 2020a) and around 20 million live within one hour of it. Arbor Low is situated near the modern day A515, a main artery through the Peak District, thereby making Arbor Low and Gib Hill commonly visited sites, and they are also popular sites for student field trips (McGuire and Smith, 2008); Arbor Low in particular is a site of spiritual interest, as previously mentioned. In the later 1990s, the owners of Upper Oldhams Farm estimated around 5000 people visited each year, and a student visitor survey recorded around 749 people visiting over 25 days during Easter, when visitor numbers were naturally higher (Booth *et al.,* 1996; McGuire and Smith, 2008).

Typically, the busiest day and night is the Summer Solstice 21st to 22nd June, though even this number was dropping off compared to past numbers; again Upper Oldhams Farm estimated between 50 and 200 people visit Arbor Low at this point, more being day visitors than campers; Sunday is also apparently the most popular time for visitors (McGuire and Smith, 2008). An EH representative admitted this number was within the 'carrying capacity' of Arbor Low and Gib Hill but having definite numbers would be beneficial, therefore a visitor-counter was installed but an important piece was stolen and was due for repair (McGuire and Smith, 2008).

Students from Buxton Community School conducted a useful visitor survey for 25 days in April 1996 (Booth *et al.,* 1996); though over two decades old now and 12 years old at the time of the McGuire and Smith (2008) Conservation Plan, it was the only visitor survey analysis done in detail. 749 people were recorded and provided opinion on their visit. They were largely family groups and 'friendship' groups, with most being aged between 25 and 59 years old, 22 % under 16 and 9 % over 60 (Booth *et al.,* 1996; McGuire and Smith, 2008). 30 % found the site from road maps and atlases, 21 % came from 'books' and 17 % had heard about the site from other people, but visiting the site was not their main purpose for the outings (77 %) and 70 % were also first time visitors (Booth *et al.,* 1996; McGuire and Smith, 2008); 44 % lived outside of the Peak District and came for a day visit, 11 % were staying for longer than a day (Booth *et al.,* 1996; McGuire and Smith, 2008). When the visitors were asked how could the experience be improved, the most 'emphatic response' was that the site should remain untouched (Booth *et* *al.,* 1996; pg. 29), with other responses including ‘please don’t spoil it’, ‘leave the site alone’, and ‘do not make it like the Cotswolds’.

During the Conservation Plan research, there was a consultation group with responses to the site; due to funding and time constraints on the report a statistically viable survey could not be carried out, however PDNPA and EH staff and some others interviewed expressed views that coincide with the visitor views of 1996 (McGuire and Smith, 2008). Atmosphere, the tranquillity of the site attracted visitors in 1996 and was reiterated by PDNPA and EH staff, and that the rugged/natural look of them was part of the appeal, as well as the long-lasting respect for the location, the relationship of human behaviour to the landscape and sky, and the sense of place that comes from it (McGuire and Smith, 2008). Being on a false crest was also a part of the appeal, as it cannot always be viewed on approach, and the wide views were also important; from Gib Hill it appeared that “every hill seemed to have a barrow on it” (McGuire and Smith, 2008, pg. 58).

Spirituality is important at Arbor Low but is far from a new phenomenon, as people have held the site in some regard since the Romano-British period, as offerings are well documented for that period and Anglo-Saxon period (McGuire and Smith, 2008). Since the 19th century, records have documented explicitly Christian events from the Primitive Methodists; one such event was recorded by Joseph Wood from Primitive Methodists of Monyash, and others flocked from miles around (Pape, 2008); Wood attended and documented a scene at Arbor Low where three preaching stands were set up in a triangle for outdoor praying, and horses were seemingly outside the henge, eating grass or hay implying people had travelled from further than Monyash barely two to three miles away (Wood, cited in McGuire and Smith, 2008).

Modern manifestation of spirituality comes through as offerings placed during the Solstices and Equinoxes which attracted up to 500 people in 1989 and 300 in 1988 (McGuire and Smith, 2008), yet the number of visitors had been decreasing over the years since. Other activities do occur as people come for contemplation and leave offerings throughout the year, or to perform ceremonies such as ‘hand-fasting’ and to spread ashes, and the owners of Upper Oldhams Farm even noted a Sikh wedding had also occurred there (McGuire and Smith, 2008).

Ley lines are also of interest to some at the site, as well as buried water and energy lines, and the UFO Society of Great Britain also used it as a base (McGuire and Smith, 2008). There is a pagan presence, in 1929 Ralph de Tunstall Sneyd, held a ceremony at Arbor Low by robed members of the ‘Bardic Circle of the Imperishable Sacred Land’, and a costumed Arthurian group continued this tradition in the early 21st century (McGuire and Smith, 2008).

3.4 Bull Ring

The Bull Ring is another henge monument, but this site is just outside the official boundary of the Peak District National Park. As a result, its history has led to more damage than at Arbor Low. It is far closer to an urban area, and though it is scheduled, it is not under any direct care beyond the local community.

3.4.1 History and Geology of Bull Ring

The Bull Ring henge is situated in what is now a recreational field in the village of Dove Holes, 5.6 km north of Buxton, Derbyshire on the A6 in close proximity to large quarries (Figure 3.8). It is damaged, lacks orthostats, but it is incredibly similar to Arbor Low in regard to size and dimensions (McGuire and Smith, 2008). Tristram (1915) acknowledged that the origin of the name ‘Bull Ring’ was unrecorded, but that it may have once been used for bull baiting, or it may have always been called ‘The Ring’ for its shape and was used as a bull field, leading to the name. Heathcote (1957) wrote that it was excavated by Oxford University Archaeological Society in 1949, with finds in Buxton Museum.

It lies at 340 m OD near to the west edge of the undulating limestone plateau, which Arbor Low is also situated on (Barnatt and Myers, 1988). It is a Carboniferous limestone, with gritstone of the Millstone Grit series to the west; 1 km to the west is the gritstone moor and it forms a high escarpment called Black Edge which rises to around 500 m. To the north-west is the only major break in the upland called Barmoor Clough which allows easy access to the Cheshire Plain, and the south/south-east between the Bull Ring and the River Wye, the area is a flat limestone plateau which was likely sought after by prehistoric farmers, and the Bull Ring is situated on a slight crest on this plateau, and can be seen up to a kilometre away (Barnatt and Myers, *ibid.*).

There are several factors that suggest that the Bull Ring and Arbor Low were constructed around the same time in 3rd millennium BCE, operated in similar ways, and their locations perhaps suggest a division the limestone plateau with the Wye Gorge functioning as a natural boundary between two territories (McGuire and Smith, 2008). Human activity at Bull Ring and its surrounding area was thought to have preceded construction of the henge; a nearby test pit evaluation at Hallsteads, a road running north-south to the north of the Bull Ring, was thought to have high archaeological potential due to the presence of the henge; the report by Oxford Archaeology suggested that findings of lithic artefacts from either the Mesolithic or Early Neolithic periods show this pre-dating (Parker, 2013).

3.4.2 The Local Landscape

The area directly to the east of the Bull Ring has been subjected to extensive limestone quarrying, particularly in the steep dry-valley of Dove Holes Dale, and in other nearby tributary dry-valleys (Barnatt and Myers, 1988). As will be seen in later images of Bull Ring, the older quarries are now re-established as parkland walks, quite wooded. Tristram (1915)'s investigation detailed to the south-east of the henge an immense excavation made by the local lime works that a few years' prior threatened to totally demolish the Bull Ring, but the danger was avoided due to exertions of archaeologists in Buxton.

Beyond the wooded area, again to the east, is a large quarry, owned by CEMEX, the Dove Holes Quarry, Asphalt Plant & Dry Silo Mortar and Buxton Concrete Plant & Dry Silo Mortar Plant (CEMEX, 2022). Another quarry lies further to the south-southeast called Tarmac Tunstead Cement Plant (Tarmac, 2022). Finally, three old, abandoned quarries lie to the south: Victory Quarry (now a lake), an unnamed quarry on the opposite side of Dale Road to CEMEX, potentially once used by the same company, and another, also lake but appears to be utilised partially as Lomas Distribution parking (Figure 3.8).

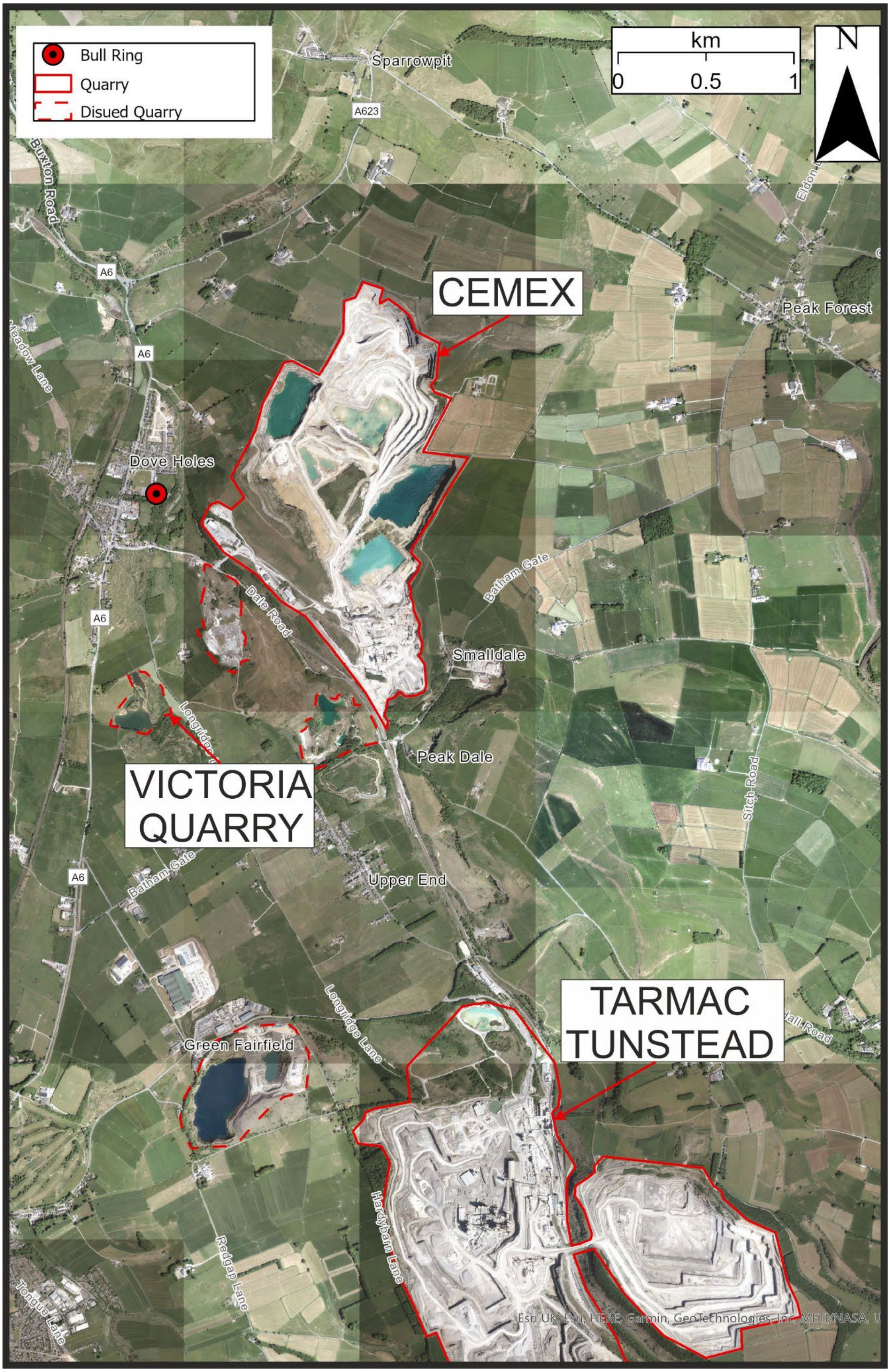


Figure 3.8: A map outlining the used and disused quarries in proximity to Bull Ring at Dove Holes, Derbyshire on the A6 (Image credit: Aerial images available in ArcGIS Pro).

3.4.3 Location and Construction

Like Arbor Low, the Bull Ring is a class II henge (Parker, 2013). It is comprised of embankments – called vallum – and two entrances oriented north to south but of differing widths. In 1915 the south entrance measured 30 feet wide and the north entrance only 13 feet (Tristram, 1915), and an internal ditch – called *fosse* - around a central plateau; the orthostats are no longer present as it is likely they were removed in the early 19th century as building material (Figure 3.9) (Tristram, *ibid.*; Barnatt and Myers, 1988). The henge had a diameter of approximately 82 x 86 m, including the embankments, the width ranged from 9 to 11 m and stood an average of 1 m tall in the 1980s, however the internal ditch had been silted and eroded, particularly in the north-east corner of the henge where quarrying occurred, but it was at least 8 to 12 m wide with a depth of anything between 0.5 to 1 m in the 1980s (Barnatt and Myers, 1988). Traces of a berm had also been found on the southern side of the site that separates the bank and ditch about 5m wide, however a berm was not noted on the north side suggesting either the embankment and ditches were closer together or it has been eroded (Barnatt and Myers, 1988).

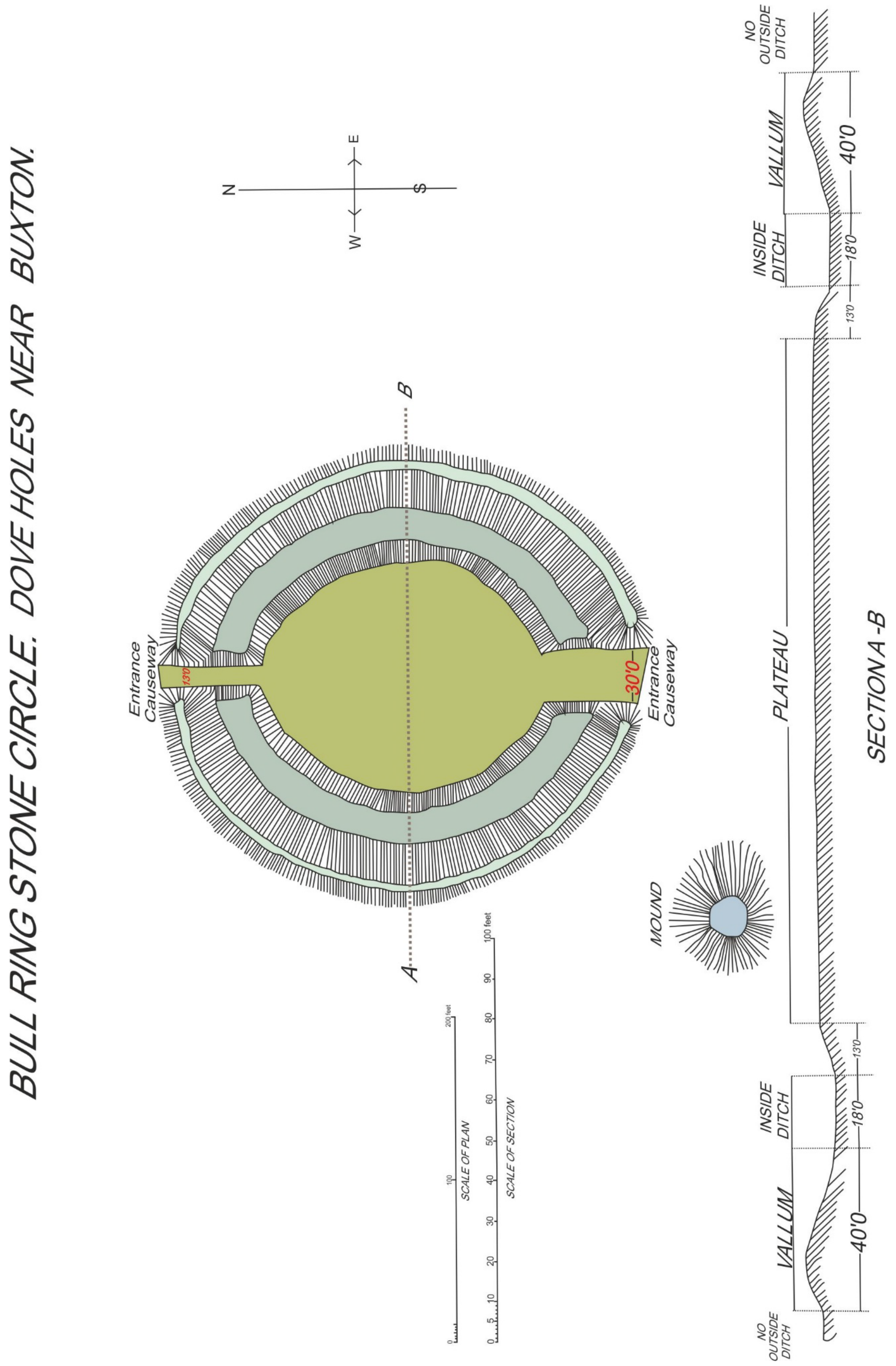


Figure 3.9: Adapted from Tristram (1915), the plan and sketch of the Bull Ring in the early 20th century.

Parker (2013) went on to provide more recent information in that it had a diameter of 93 x 90 m, the ditches ranged between 8 and 12 m wide, and 0.5 to 1 m deep. Parker (2013) also noted that an excavation completed in 1949 by Alcock (1950) proffered a width of 5 to 6.5 m and a depth of between 1.2 and 2.1 m. This was echoed by Barnatt and Myers (1988).

It is also interesting that Arbor Low and the Bull Ring may share one other characteristic: the presence of a possible barrow in the immediate area: at the Bull Ring it lies 20 m to the immediate south-west of the henge that stands to about 1.5 m high and has a plan of 27 x 21 m (Barnatt and Myers, 1988; McGuire and Smith, 2008; Parker, 2013). It was offered by Parker (*ibid.*) that a round barrow was superimposed on the western end, akin to Gib Hill and a few other examples in the Peak District.

Unlike Arbor Low, as of 1915 there did not appear to be any record of official excavations at Bull Ring (Tristram, 1915), however a Mr John Ward did cut a "*tentative trench through the ditch…discovered a fragment of early earthenware*" (Tristram, 1915, pg. 79), but this was provided by word of mouth rather than an official record. Other evidence of excavation were some holes on the north-east side of the central plateau, but these may have been from people attempting to mine lime or stone for agricultural reasons. Alcock (1950) completed an excavation in 1949 and found several flint flakes and the rim of a food vessel. Barnatt completed another excavation in the 1980s, finding flint flakes, a sherd of Roman pottery and a post-medieval material that was associated with ploughing (Barnatt and Myers, 1988).

The construction of henges, including Stonehenge, Arbor Low and the Bull Ring, has long been associated with astronomy, in so far as the plan that stone circles appear to have is that they, as Tristram (1915, pg. 81) defined, "*a relation to the rising of the sun at a certain season of the year*" such as midwinter and midsummer; Barnatt and Smith (2004) and McGuire and Smith (2008) do allow that there may have been an astronomical alignment in play in the construction of the henges but McGuire and Smith (2008) also suggest this could merely be fortuitous.

However, this mere suggestion is enough that those involved in what McGuire and Smith (2008) call 'modern spiritual engagement' commonly held events at solstices; many people visit henge because they feel they have a spiritual relationship with them and this takes on many forms, and it most likely continues a practice that has been ongoing since they were built (McGuire and Smith, 2008).

3.4.4 Land Use

As has been outlined in Section *3.5.2*, the local area has been and still is used for quarrying. Human activity does extend back into history before construction of Bull Ring, across the area (Figure 3.10).

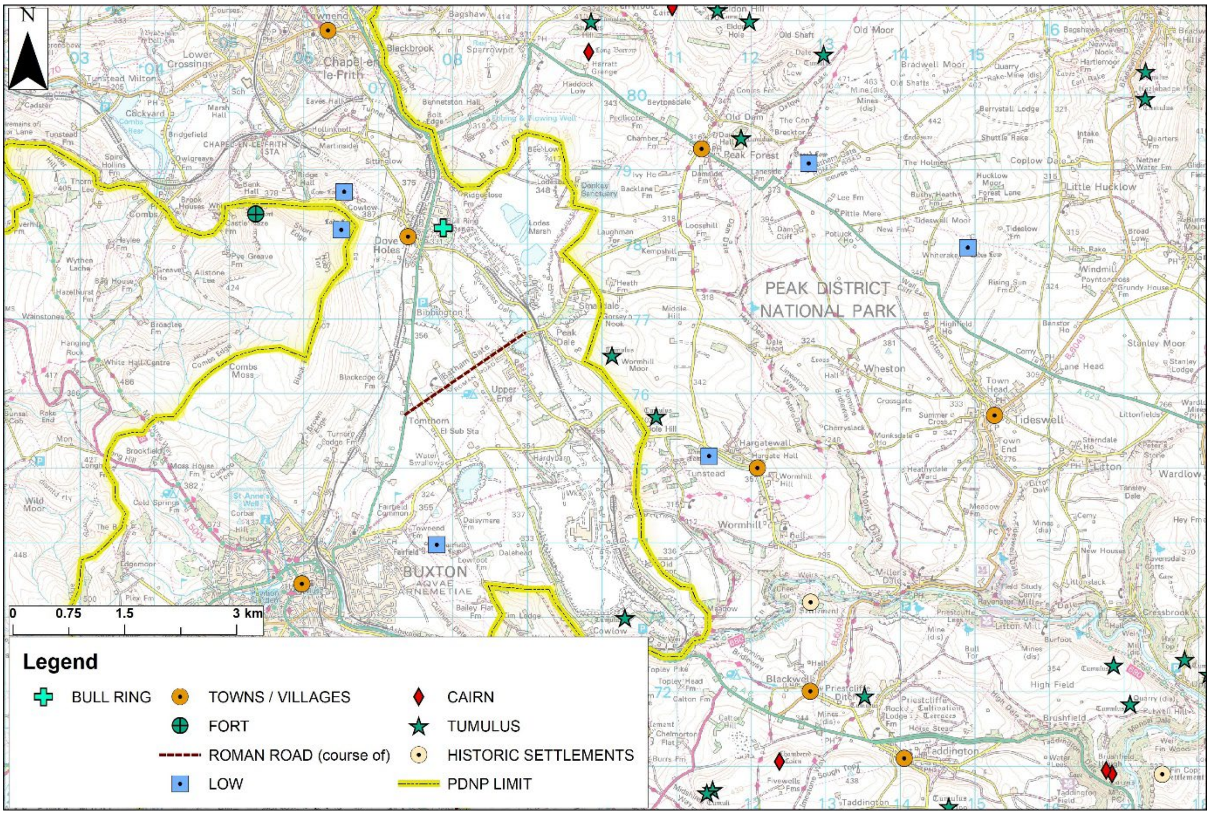


Figure 3.10: Other prehistoric and historic features near to the Bull Ring, which sits outside the limits of the Peak District National Park (yellow line) but is situated on the same limestone plateau as Arbor Low to the south-east.

3.5 Pilsbury Castle

Pilsbury Castle is a Norman castle from either the 11th or 12th century, comprised of a motte and two baileys, sat in the Dove Valley 0.5 km north of the ancient hamlet of Pilsbury, Derbyshire which is 2 km north of the medieval market village of Hartington, Derbyshire. The River Dove flows southwards on the western side of the site and is the border between Staffordshire and Derbyshire counties (Figure 3.11) (Landon *et al.,* 2006). It is one of the best surviving Norman castles of the few that exist in the Peak District (Barnatt and Smith, 2004; Barnatt, 2019), became a scheduled monument in 1937 (Historic England, 2020) and was bought by the PDNPA in order to better protect it sometime after 1991 (Landon *et al.,* 2006).

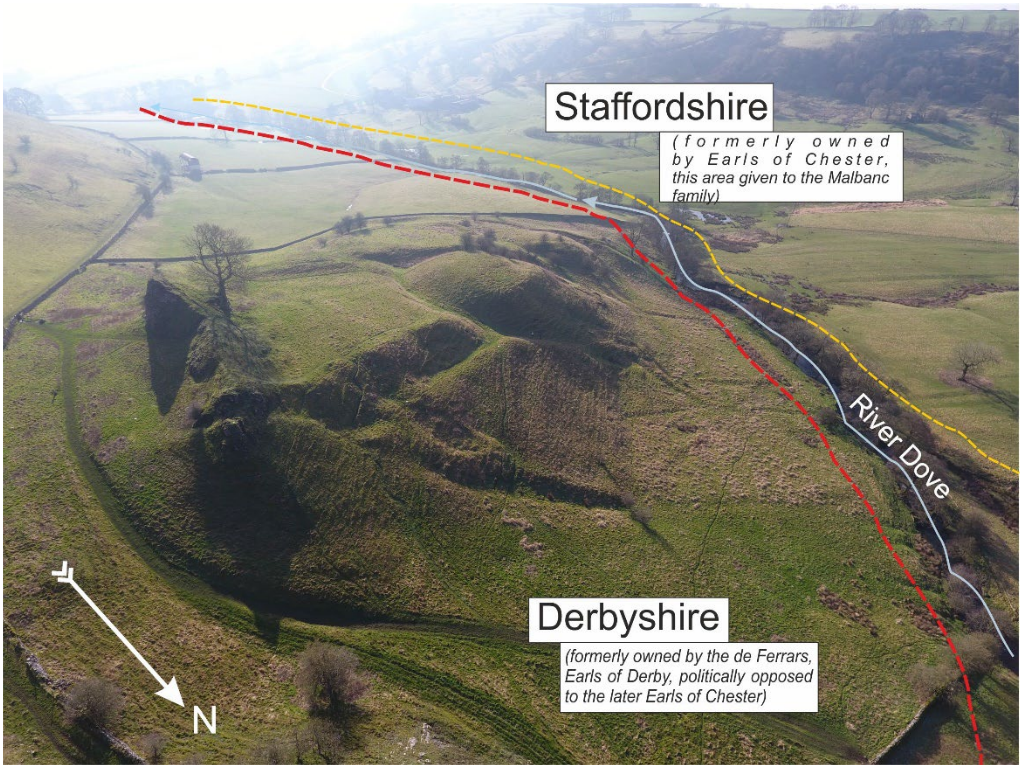


Figure 3.11: An oblique aerial view looking south at Pilsbury Castle, February 2020. The River Dove can be seen to the right, forming the border between Derbyshire (left) and Staffordshire (right). The reef atoll outcrop to the far left is resistant to weathering compared to the rest of the site (Source: Author's own work).

3.5.1 History and Geology of Pilsbury Castle

Geologically, Pilsbury Castle is situated near the boundary of what is termed the White and Dark Peaks, or more appropriately the South West Peak - which comprises a landscape very similar to the Dark Peak but in a "more intimate mosaic" as described by the PDNPA (2020c) of hedges, heathland, bogs, wood-, grass-, and wetland on ridges, slopes and plateaux which is closely managed. Specifically, the Dark Peak refers to the northern and eastern regions of the park from Chapel-en-le-Frith at the southern limit to Stanage Edge to the east, and Marsden and Meltham, Lancashire as the northern limit (PDNPA, 2020d); however, the term can also refer to any region of the park that is not the central White Peak. Typically, the Dark Peak is formed by mudstones and sandstones of the Millstone Grit Group, from the Namurian stage of the Carboniferous, 313-326 mya (Hose, 2017). The Carboniferous limestones of the area are hard and quite impervious, but water does percolate through a well-developed system of joints (Weston, 2000). The Bee Low limestone is the most extensive outcrop in the White Peak Plateau, laid in the Visean stage shallow tropical sea and formed a shelf and resultantly, a succession of quarries mine this area (Weston, 2000). It is this limestone that forms the steep side of the eastern bailey at the site.

The land on the eastern side of the River Dove was owned by the de Ferrers family after the arrival and crowning of William the Conqueror in 1066; in the Domesday Book a substantial amount of the land around Hartington and in its extensive parish, or Quarter, was considered 'wasteland' but was clearly improved (Barnatt, 2019). Henry de Ferrers may have been the individual who built the castle as he had "*a group of manors in the Peak*" (Beresford, 2010, pg. 16). The position of Pilsbury Castle would have been quite central in the Dove Valley (Barnatt and Smith, 2004) and so it was likely constructed part way down the valley-side not as a position of defence, but more for administrative purposes and as an initial focal point for their border, defined by the River Dove, approximately 120 m to the east (Figure 3.11). They moved the administrative power towards Hartington when it received its royal market charter, but this power did not last – the de Ferrers lost all of their land after a failed rebellion against Henry III in 1266 and its ownership was taken up by the Earl of Lancaster (Weston, 2000; Barnatt, 2019).

Pilsbury sits within the Parish of Hartington, more specifically in the Town Quarter (Barnatt, 2019). The area has long been in use, but post-Conquest of 1066 the area was given to the de Ferrers family, Earls of Derby, by King William (Weston, 2000; Barnatt, 2019). Henry de Ferrers was given Hartington as part of the 'Manor of Duffield' which included Hartington, Belper, Duffield, Holbrook, Alderwasley, Southwood, Heage, Idridgehay, Hulland, Biggin, Ireton, Bonsall, Brassington, Matlock, Spondon, Scropton, Wirksworth, Ashbourne, Duffield Forest and the Hundreds of Wirksworth, Sutton and Appletree, Repton and Gresley (Weston, 2000).

Pilsbury, though now a small hamlet, was also home to a monastic grange; Robert de Ferrers, 2nd Earl of Derby, was a benefactor of the Cistercian Order and founded a monastery at Merevale in Warwickshire, and endowed lands that included holdings at Pilsbury and nearby Cronkston; these monastic farms became known as granges, and both Cronkston and Pilsbury Granges are stilled named on present OS maps.

Pre-Conquest, the area was owned by a landlord named Alfsi, and there is no earlier documentation of the area before the Domesday Book in 1086. The name 'Pilsbury' is Anglian: '*burgh'* in Old English translates to 'fort' or 'fortified place', and '*Pil'* is most likely a person's name, therefore the name means '*Pil's fortified place*' (Weston, 2000); this may imply that there may have been some other kind of structure or Anglian presence in that area prior to the Norman period motte-and-bailey castle between the late 6th to early 11th century (Barnatt, 1991a; Weston, 2000). The hamlet is mentioned, in conjunction with nearby Ludwell, in the Domesday Book, and in 1262 there is another reference to the hamlet with regard to a charter, signed by Robert de Ferrers, 3rd Earl of Derby to Henry of Shelford of 100 acres and witnessed on 25th January at Pilsbury (Landon *et al.,* 2006).

Landon *et al.,* (2006) completed a full survey of Pilsbury in 2006 jointly with ARTEAMUS from the University of Sheffield. Magnetometry and resistivity was conducted, and provided 4,000 readings, alongside a contour survey using a total station, and in doing so they found there is no single point at the site to see it in its entirety (Landon *et al., ibid.*). The hachure plan (Figure 9.10) was created from 2,000 recorded points from a grid of nine control points, and lastly some aerial photography was gathered (Landon *et al., ibid.*).

Pilsbury Castle's east bailey (Figure 3.12) had a rudimentary wall constructed across its eastern most edge that made use of the natural reef atoll (Landon *et al.,* 2007). Predominantly, the site is situated on the Bowland Shale Formation (British Geological Society, 2020), rested on an uncomformable surface at Pilsbury. In 2006 the site was not prone to landslips (Landon *et al.,* 2006), yet there has been a small landslip in recent years on the west-north-west side of the motte according to PDNPA, and during 2020 data collection, the southernmost end of a hollow-way was being severely damaged by badger sets.

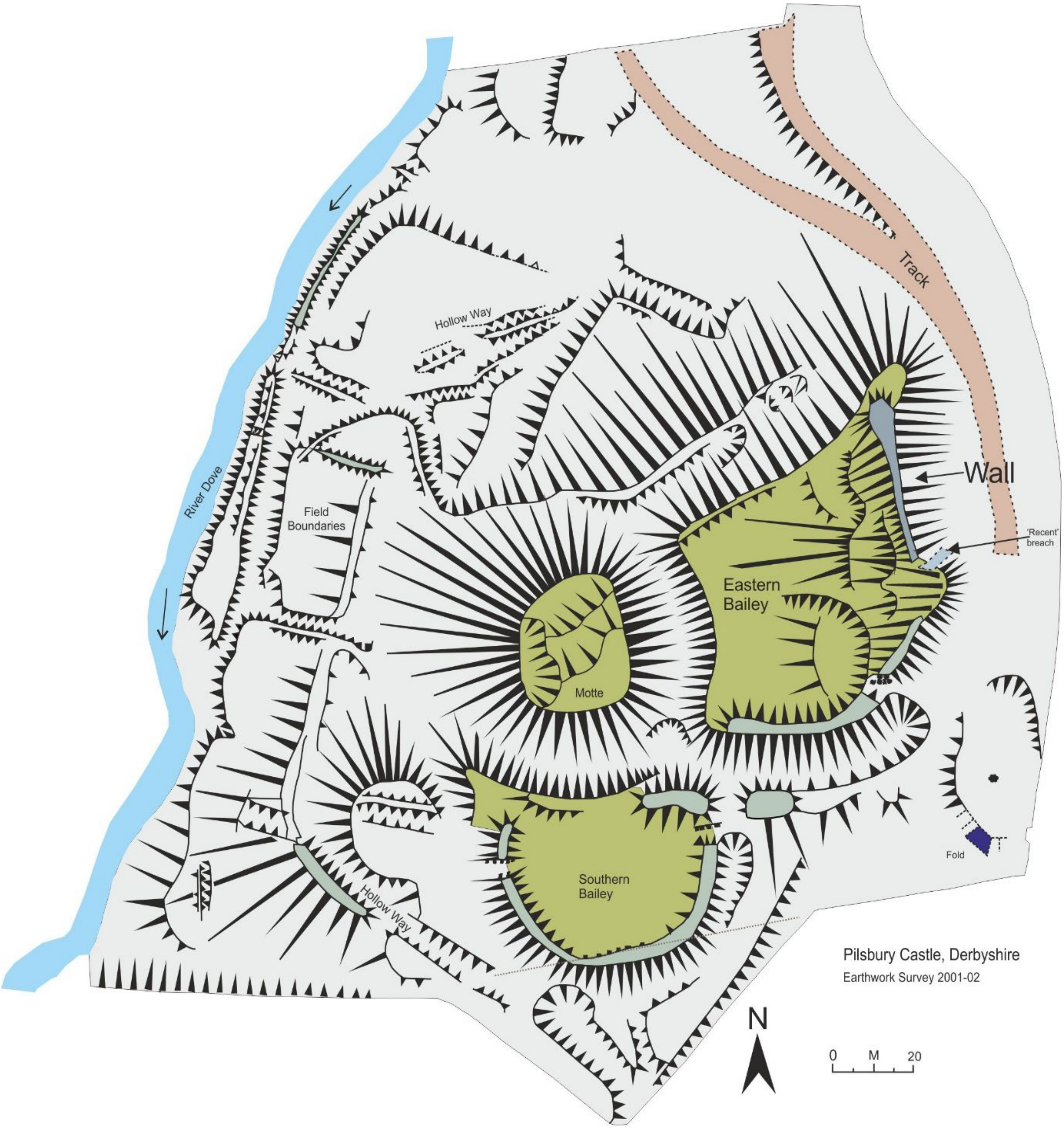


Figure 3.12: A hachure plan of Pilsbury Castle, Derbyshire. Adapted from Landon et al., (2006).

3.5.2 The Local Landscape

Not only are there the three main earthworks of the motte and baileys, but there are a considerable amount of smaller earthworks at the site. Between the river and the site, there are extensive medieval field systems, of which there are many throughout the Peak District, for example some near the village of Longnor, approximately 3 km to the north-west of Pilsbury Castle (Barnatt, 2019).

The most distinctive of the smaller earthworks at Pilsbury is a bank and broad ditch alongside the river stretching for about 70 m, and there is a number of smaller banks that run from the motte towards the river in this area (Figure 3.12) (Landon *et al.,* 2006). Many are described as being at right-angles to the river with a single one having a 'Y'-shaped end at the east, but to the west it runs diagonally and potentially overlie another bank. The 70 m long linear bank has been theorised to be a fishpond, used as a source of food for the garrison in the castle; Landon *et al.,* (2006) deemed this unlikely, and other theories have been considered unlikely such as flood defences or a defensive outwork for the castle itself. Between Pilsbury and Hartington there is evidence that the river course has changed, so this linear feature may be a palaeo-channel (Landon *et al.,* 2006).

The other, slighter features do have firm explanations and are thought to be former field boundaries or small stock enclosures, some pre-date the track that goes out onto the floodplain and some overlie it, and are therefore younger (Landon *et al.,* 2006*)*; there is no real connection that can be made between these features and the castle temporally.

3.5.3 Construction, Location, and Abandonment

The earthworks at the site have been fashioned out of already present natural features and a reef knoll outcrop; a substantial ditch separates the motte and both baileys, and it appeared the soil from this ditch was piled onto an already present mound to increase its prominence in the centre (Landon *et al.,* 2006). The two baileys also have ditches and banks, with the eastern bailey being the most prominent due to the presence of the limestone apron reef atoll on its eastern edge, but the site itself is more substantial on the northern side where it naturally falls sharply to the floodplain below (Landon *et al.,* 2006).

The eastern bailey is sub-rectangular (Barnatt, 1991a) and protected by the apron reef on the eastern side at circa 5 m high. Barnatt (1991a) measured this bailey to be 55 x 45 m across with a ditch to the north and west, and a ditch and slight internal bank at the south. There are only two potential entry points on this bailey, one being a narrow gap at the south-east corner (Figure 3.10); this breach was interpreted by Barnatt and Smith (2004) as an entrance into the castle but indeed the segment there looks more recent in age, possibly cut by farmers for better access across the site, a potential that was later recognised by Barnatt and Smith (2004). Access may also have been granted by a bridge from the southern bailey or from the motte to the western side (Barnatt, 1991a). There are very faint remnants of a track within the enclosure of the eastern bailey that leads towards the motte which may have led towards another bridge reaching across to the motte and its summit but this remains uncertain; the southern bailey may have been constructed for the defence of the entrance, or to house workshops or livestock (Landon *et al.,* 2006).

Internally there are some alterations in level which may indicate buildings; the most convincing being the flat platform in the slope that could have had a 15 x 10 m building, and a yard along the northern edge, somewhat larger, may also have had a building (Barnatt, 1991a). Landon *et al.,* (2006) however, documents an area of 8 x 4 m and smaller areas, comparably indistinctive that are harder to measure; the geophysics conducted in 2006 failed to distinguish their presence though conditions were not favourable (Landon *et al.,* 2006). Other than these small sections, Landon *et al.,* (2006) suggested that despite some deliberate flattening, the contours are largely natural.

Along the top of the eastern reef knoll is the fragmented remains of a primitive rubble wall held with lime mortar tempered with chopped straw are known; there is no certain way to date the wall, but the use of straw for tempering lime mortar was a technique used in the medieval period, and there is no other explanation for its existence at the site (Landon *et al.,* 2006). Landon *et al.,* (2006) does theorise that the presence on the wall on the outcrop is likely for stabilising a wooden beam for a palisade attachment, as there is no evidence of a beam slot existing in the limestone. The other physical evidence of stone construction is at the south-western corner of the eastern bailey where there may have once been an entrance with revetted ground to prevent slippage from the motte into the ditch (Landon *et al.,* 2006).

The defences are best preserved at the eastern bailey as well; on its northern side the contours are already steep because of the outcrop but added to it is a bank and external ditch, which alongside a palisade would have created a formidable obstacle (Landon *et al.,* 2006). On the eastern side of the east bailey is the steep and angular outcrop, to the south is another bank and external ditch, and to the west is the ditch separating the motte (Figure 3.12) (Landon *et al.,* 2006).

The southern bailey, however, is not as prominent; it comprises lower banks with an external ditch, around an undulating surface with no building traces (Landon *et al.,* 2006). Barnatt (1991a) measured it at circa 40 m across and is semi-circular in shape; there is a flat face on the northern side, separated from the motte by a deep ditch, but the rest is defined by an internal bank. The actual position of the entrance is hard to determine, but it may have been at the north-west side of the southern bailey, approached by two hollow-ways – though it is considered to be a more recent disturbance (Barnatt, 1991a), as there was a smaller low mound that may once have housed a gatehouse, if indeed this breech was an entrance, however there had been rabbit-derived damage here that prevented interpretation (Landon *et al.,* 2006). From this gatehouse a bridge may have led from it to the other bailey as the nearest side of the eastern bailey stops short of the ditch and has trace evidence of a stone revetment on the corner, lending support to the bridge interpretation (Landon et al., *ibid.*). The second theory was the entrance lay on the south side of the limestone knoll, but this was also considered a recent breach (Landon *et al., ibid.*).

The motte is the most prominent of the earthworks at Pilsbury Castle; it is central, as most mottes tend to be in motte-and-bailey castles, and is considered to have an irregular summit with a diameter of approximately 30 m (Barnatt, 1991a); this irregularity could be interpreted as later disturbance. It is described by Landon *et al.,* (2006, pg. 88) as “rising steeply from the floodplain” with substantial ditches separating it from the two baileys. The spoil from the creation of these ditches was likely to have been added to the motte to raise the height of the motte, which has trace evidence of a building or watchtower on its summit though no surface signs remained (Landon *et al.,* 2006).

Access up and into the castle was via the so-called ‘hollow-ways’ (Figure 3.12 and Figure 3.13). A considerable hollow-way leads up between the defences and the River Dove; in the south of the site it can be followed as a spur from the main path that leads to the hamlet of Pilsbury, yet in the north it does not appear to follow along the floodplain but did appear to have been continued about the north side of the prominent earthworks to join a track on ground rising to the east, and the evidence of it faintly remains (Landon *et al.,* 2006); it is likely that this was to make people of the time walk around the most prominent parts of the castle to make it appear more imposing.

Figure 3.13: Oblique aerial view showing the hollow-ways, possible field or canal boundaries, and the wider earthworks at Pilsbury Castle, February 2020 (Image credit: Dr Alex Nobajas/Helen Malbon).

There is a track that was marked on early Ordnance Survey maps as active, and still is into the 21st century; it parallels the River Dove and travels in a northerly direction to Crowdicote, Glutton Bridge, The Stannery and Dowel Dale all on the Derbyshire side of the river (Landon *et al.,* 2006). There is also a ford from the path that crosses over the River Dove on the Staffordshire side called the Stepping Stones, about 700 m north and can be seen from the castle. It was suggested that another ford existed closer to the site but there are no signs that one ever did, therefore it is thought that the castle guarded north-south travelling traffic (Landon *et al.,* 2006). Strangely, however, the pathways of medieval origin in this area commonly crossed over the river rather than ran parallel to it, such as the one in the hamlet of Pilsbury and Hartington to the south (Landon *et al.,* 2006).

Hart (1981) suggested that the construction developed over time, but only excavation will answer this question (Landon et al., 2006) and so far there does not seem to have been any excavation completed in the last two centuries; of the visible earthworks at the site, all are of post-Conquest (1066) in age. However, the name of the castle and the nearby hamlet can be translated to ‘Pil’s fortified place’, fortified coming from the Old English word ‘burgh’, which can occasionally mean ‘hall’ – these were significant buildings in the Anglo-Saxon period, 6th/7th centuries to the 11th century (Landon et al., (2006). There is also every possibility that the Norman landowners simply took the name of the closest settlement and that there is no pre-Conquest castle or construction here (Higham and Barker, 1992; Parsons and Styles, 2000).

It is unusual for there to be two baileys in a motte-and-bailey castle and it has been suggested that the southern bailey may have been the primary earthwork at the site that was then incorporated into the design of the motte and eastern bailey (Landon *et al.,* 2006). Barnatt (1991a), noting the circular shape of the southern bailey, suggests that it may be an early Norman ringwork constructed before the rest of the castle; there is a comparable one at Camp Green near Hathersage, Derbyshire, approximately 22 km to the north-east (Hodges, 1980). Hart (1981) and Barnatt (1991a) theorised that they were of two different timeframes; Barnatt has since changed opinion on this theory (Barnatt and Smith, 2004).

If it is a Norman timber built castle, then construction is likely to have taken place in the years following the conquest in 1066 and the widespread insurrection; for example, rebellion in Mercia led to the ‘Harrying of the North’ from AD 1069 to AD 1070, which decimated the region, brought about poverty, starvation and outlawry, thereby resulting in the construction of timber castles (Landon et al., 2006). Weston (2000) suggested that the castle may have been built between AD 1070 and AD 1080 to curb the banditry, yet others have disputed this theory due to the Harrying. If King’s Men had ruined the lands of the favoured de Ferrers family then it is highly unlikely that lone manors would have been left but that appears to have occurred, because at nearby Tissington was still productive at the time of recording (Landon et al., 2006); however, this may have simply been down to how manors were structured and depopulation carried out selectively that spared Tissington.

The next theory is that it may have been what was called an ‘adulterine castle’ (Landon et al., 2006). The proximal River Dove was, and still is, the border between Derbyshire and Staffordshire, and in the 11th and 12th centuries it was the border between the lands of the de Ferrers family and the Malbanc family, barons of Nantwich and vassals of the Earls of Chester. Between AD 1135 and AD 1153, Ranulf de Gernon was the Earl of Chester and relations were tense between the two nobles during a period of unrest and civil war called ‘The Anarchy’ – de Gernon declared for Empress Matilda, whereas Robert de Ferrers, 2nd Earl of Derby, was for King Stephen (Landon et al., 2006). Hundreds of castles were hurriedly constructed, termed ‘adulterine’ as they were not built with royal consent; consequently, many were not recorded, some were razed once the fighting had ended, and others were slighted but not all (Landon et al., 2006). Pilsbury may have been an adulterine castle, however they were commonly much more hurried in design, thereby making them less substantial which is contrary to what is observed at Pilsbury (Landon et al., 2006); if not for this particular period of unrest, then it is entirely possible to castle was built during another period of tension.

It does appear however, when it’s positioning is considered, that the castle may have been implemented for a more administrative role than martial; its position made it a focal point in the de Ferrers’ lands and likely became a place to ‘control’ the local populace before power was transferred to Hartington (Landon et al., 2006). This is quite likely due to the very central position it holds in the de Ferrers’ lands (Landon et al., 2006); the landscape lent itself to use such as the easily modified shaley floodplain and the defensive reef knoll on the eastern bailey; there were also at least two fords across the River Dove, which at this location is easily manoeuvrable (Landon et al., 2006), and the high limestone plateau – the White Peak – that overshadows the castle is not significant and at this time siege warfare was not as much of a concern (Landon et al., 2006).

It is one of perhaps three motte and bailey castles built along the riverside; one is extant at Bank Top, approximately 3 km south of Pilsbury; only the motte exists (Barnatt and Smith, 2004) and measures around 20 m with a 2.5 m deep rock cut ditch (Landon et al., 2006). Hurford and Sheppard (2005) also suggested that another motte and bailey castle existed at Crowdicote, nearly 2 km to the north-east; this suggestion is backed up by Turner (1903, pg. 162) "there are remains of foundations of an old castle", though Turner may be referring to Pilsbury when he describes what items were found such as a silver coin from Henry III's reign (Turner, 1903), but a house has since been built on the theorised site. The question posed by Landon et al., (2006) was are these part of a defensive network constructed by the de Ferrers family – if the third did exist – or are they from different periods in time?

When it was abandoned is another question that lacks evidence to provide a suitable answer; by the mid-12th century the timber castles had largely been rebuilt from stone (Historic England, 2018a) and became over-tower keeps (Landon et al., 2006) and if no rebuilding did take place then the castles would fall into disrepair (Rowley, 1983). Consequently, if Pilsbury was significant then it should have been rebuilt into stone, which there is no evidence of. It appears that the support was transferred to Hartington by the de Ferrers family (Coates, 1965) and since Pilsbury Castle was not visible from the village, it further enforced the decline in importance.

The dates of abandonment do vary; a suggestion was AD 1200 but there was a charter in AD 1262 that was witnessed at Pilsbury by the Earl's brother, a person of importance (Jeayes, 1906; Landon et al., 2006). A charter must have been signed in a building of significance, which may advocate the castle was in some use by AD 1262, or there was another significant building in the area, such as the Grange, or even an older, pre-Conquest Anglian hall that retained importance (Landon et al., 2006).

Ultimately, the castle may have been in use for approximately 124 years and was perhaps intended to become a more substantial place of power for the de Ferrers family until Hartington received its Market Charter in AD 1203 from William de Ferrers (Coates, 1965) when it likely fell into disrepair and what remains today is possibly how it has been for over 800 years.

3.5.4 Preservation of Pilsbury Castle

Pilsbury Castle is under direct ownership of the PDNPA in order to better ensure preservation. In 1991 an archaeological report was completed of Pilsbury Farm – under which Pilsbury Castle comes under - by J. Barnatt at the request of the owner, as part of an assessment for the Farm Conservation Scheme (Barnatt, 1991a). Any discoveries were documented on a 1:2500 OS basemap – standard survey – but at the time of the report there was extensive amounts of snow in the valley bottom that limited this.

Pilsbury Castle is a Scheduled Monument, scheduled on 13th October 1937 (Historic England, 2020). It was designated because it is considered to be of national importance and has suffered comparatively little disturbance since its abandonment (Historic England, 2020).

The Sites and Monuments Record (SMR) had at the time recorded the majority of the main features that were inspected in the report, but were far from adequate, with the exception of Pilsbury Castle (record number SMR 6857) and two barrows (Barnatt, 1991a). The 1991 survey recorded three more significant sites, comprised of ancient cultivation terraces, a medieval grange boundary and a medieval hollow-way (Barnatt, 1991a), as well as 26 minor features and three groups of existing buildings that also had not been recorded by the SMR.

3.5.5 Monument Condition

During the fieldwork at Pilsbury Castle in February 2020, the castle looked to be in good condition, but it was realised that an issue pertained to the outer work below the southern bailey, closer to the river. Here was extensive damage caused by badger sets that could destroy the integrity of the earthwork in the section of the site (Figure 3.14).

Figure 3.14: As of February 2020, there was badger set damage on the south-western hollow-way at Pilsbury Castle (Image credit: Dr Alex Nobajas/Helen Malbon).

The eastern bailey reef knoll withstands erosion, however people do climb it as it has a spectacular vantage point of the valley north and south of the castle. Consequently, the outcrop and soil have been smoothed or eroded by walkers climbing up to the precipice. In the last decade there has been some efforts to keep walkers from walking across the reef knoll; Historic England in conjunction with the PDNPA erected signs asking the public to be considerate in regard to conservation efforts to prevent further damage, as per the PDNPA.

On the eastern side of the motte mound, a fence had been constructed by the PDNPA after there had been a small landslide, in order to define the area, and to keep livestock and walkers away from it to allow the grasses to take root in hopes of firming the soil.

The southern bailey is not as prominent as the eastern bailey, and in the 1990s a boundary wall did separate it from the rest of the site, and that area had been ploughed alongside breaches recently created to allow for farm vehicle passage (Landon *et al.,* 2006).

3.5.6 Land Use

The southern bailey has seen some damage from farming, though the topography has dissuaded ploughing, the southern bailey was ploughed in the recent past as a section was separated from the site by a field boundary – since removed – but was grazed by sheep; overall the site is reasonably well preserved despite the shale it was built on (Landon et al., 2006). At the point nearest to the eastern bailey, there is a low mound which has been damaged by rabbits, impacting interpretation (Landon et al., 2006).

It is owned directly by the PDNPA in order to better preserve it - Historic England (2020) consider it to be very well preserved – and the land is monitored, shrubs and other growth are carefully kept back and animal presence is also monitored as closely as is possible. Recently there was a landslide on the motte, which was fenced off in order to discourage people from walking on it and to encourage growth of grasses that can hold the soil together to prevent another slip, per the PDNPA.

There is a public footpath that extends north-south from either side of the field in which the castle sits, and there are smaller paths that lead up onto the motte and baileys, though some of these may be sheep tracks as they do still graze on the site, per the PDNPA. It appears to be a well-travelled route as it is sign-posted and advertised online as a walk suggestion for those visiting this area of the Peak District (PDNA, 2020g).

Chapter 4 Methodology

4.1 Introduction

This chapter covers the workflows that were devised for this investigation in three stages:

- Permission from landowners to fly and collect photogrammetry
- Data alignment and 3D model generation
- Data analysis and 3D reconstruction

The main focus of this investigation is the use of UAV-derived aerial imagery in conjunction with GIS software for volumetric analysis and documentation of earthwork features and sites in the Peak District. The secondary focus is to virtually reconstruct these sites – hypothetically – using remnant heights and depths of the contemporary data, and from archaeologists' estimations to aid in visualisations of heritage landscapes for both research and public consumption. This methodology was created by refining what the author had previously developed for a master's thesis (Malbon, 2017) that was similar but not easy to follow; therefore, this smoother and more efficient methodology was devised to use with new data.

4.2 UAVs and Aerial Imagery

4.2.1 Unmanned Aerial Vehicles (UAVs) Technical Abilities

Using a UAV is a cost-effective tool in comparison to traditional aerial data collection techniques using helicopter and aeroplanes, as was outlined in Chapter 2. UAVs are frequently used in research for applications such as forest fire monitoring (Casbeer *et al.,* 2006), archaeology and documenting landscapes as a whole (Eisenbeiss, 2006; Everaerts, 2008), can be used for everyday planning at excavations (Rinaudo *et al.,* 2012), and glaciology in Bhardwaj *et al.,* (2016)'s study, in which they used a UAV as a remote sensing platform. UAVs are considered easy to deploy, often have inbuilt cameras, and they have the potential to carry alternative sensors for data collection, such as LiDAR and thermal imaging cameras (Chase *et al.,* 2011; Colomina and Molina, 2014). Researchers similarly acknowledge another useful aspect of UAVs is that they are suitable for flying in hazardous or hard to reach areas and can collect data with a good level of repeatability (Everaerts, 2008; Brutto *et al.,* 2012; Stal *et al.,* 2014; Ilci *et al.,* 2019).

There are three types of UAV: rotary wing, fixed-wing and hybrid, and have been used in various investigations across many disciplines: geological mapping (Nesbit *et al.,* 2018), forestry (Puliti *et al.,* 2015) and agricultural studies (Primicerio *et al.,* 2012; Zhang *et al.,* 2012). In certain research situations, such as geological mapping, fixed-wing UAVs tend to perform better than their rotary wing counterparts (Nesbit, *et al.,* 2018), as fixed-wing UAVs are able to cover larger areas of interest much quicker (Tahar and Ahmad, 2012; Nex and Remondino, 2013), however they do require a large enough runway in order to take off and land (Eisenbeiss and Sauerbier, 2011). Fixed-wing UAVs have substantial amounts of endurance and can use solar power to keep them flying, but they need to have a low mass system and continual airflow in order to gain lift and stay airborne (Everaerts, 2008; QuestUAV, 2019). Rotary-wing UAVs do not require runways as they have vertical take-off and landing capabilities (Nex and Remondino, 2013), can hover and are very manoeuvrable (Fraser and Congalton, 2018), therefore small or single sites are best for rotary-wing UAVs (Tahar and Ahmad, 2012). QuestUAV – a UK drone manufacturer – listed the advantages of rotary and fixed wing UAVs.

Fixed wing UAVs (QuestUAV, 2019):

- Have simpler construction design, meaning less complicated maintenance routine and repairs.
- Design allows for efficient aerodynamics for longer flights at higher speeds.
- Carry greater payloads, e.g. large sensors.
- Need runways to take off and land.

- Cannot remain stationary.

Rotary wing UAVs (QuestUAV, 2019):

- Blades are continually moving so no need for constant movement.
- Take off and land vertically.
- Can hover and perform manoeuvres at differing angles, best for inspection work.
- Greater electronic and mechanical complexity, meaning more complex maintenance and repairs.
- Lower speeds and shorter flight ranges.

The final type of UAV is the hybrid. The hybrid UAV combines the beneficial features from fixed- and rotary-wing UAVs, meaning it can take off and land vertically, and has speed and endurance (Saeed *et al.,* 2015; Fraser and Congalton, 2018). Hybrid UAVs are further subdivided into tail-sitters and convertiplanes (Saeed *et al.,* 2015). These types, however, are not overly common in commercial use in comparison to other types but there has been an increase in interest (Saeed *et al.,* 2018).

Convertiplanes take off, land, cruise and hover with the reference line remaining horizontal, meaning the main body configuration does not alter during the flight, and there is a multitude of transitional mechanisms the achieve the change over from horizontal to vertical flight (Saeed *et al.,* 2015). These are then subdivided again into tilt-rotors, tilt-wings, rotor-wings and dual-systems. Tail-sitters take off and land vertically with the whole aircraft tilting forward using differential thrust to achieve horizontal flight and are so named because they land on their tails; this means they require longer tails that survive the impact of landing (Saeed *et al.,* 2015). This design is mechanically simple as it does not need to have extra actuators to make the transition; this makes them lighter in comparison to convertiplanes (Saeed *et al.,* 2015). Like convertiplanes, tail-sitters are also further subdivided into Ducted-Fan UAVs, CSTTs (Control

Surface Transitioning Tail-Sitters)/DTTTs (Differential Transitioning Tail-Sitters), and reconfigurable wings (Saeed *et al.,* 2015).

The argument of this investigation, Tahar and Ahmad (2012), Lindner *et al.,* (2015), Stek (2016), Federman *et al.,* (2018), and others is that UAVs are versatile, inexpensive, and expedient equipment for documentation and recording in heritage, and in other research investigations such as agricultural studies, forestry, landslide monitoring and for commercial uses like cinematography (Lindner *et al.,* 2015;). This does not mean that UAVs do not have problems:

- Payload
- Battery life
- Flight time
- Going rogue
- Weather susceptibility

The payload, or the weight a UAV can carry, is dependent on the size of the UAV and the battery life. Smaller UAVs have a limited payload, meaning it is unlikely they can carry extra sensors (Matikainen *et al.,* 2016), such as LiDAR or thermal imaging cameras. Larger UAVs have larger payloads and longer flight times (Stal *et al.,* 2014), but the more weight that is added to the UAV, the shorter the battery life (for those that use batteries) and the shorter the flight time, but this is being rectified as technology continues to improve. Hardware and sensors could be built to be smaller, but still as efficient with high resolution, therefore they can fit to a UAV without going over the payload limit nor affecting the battery life (Lindner *et al.,* 2015). Inclement weather such as fog, wind, and rain prevent UAV flights as they can be damaged by bad weather, and if they crash they can cause serious damage (Rapp, 2009). Many UAV platforms require good weather or in the very least, calm days with level illumination, and this is not always achievable in many regions of the world (Hakala *et al.,* 2013). Lastly, UAVs require

RF and/or Wi-Fi to fly (model dependent); if communication is lost between the UAV and the controller, some UAVs do have a ‘return home’ feature to mitigate potential crashes such as DJI UAVs (DJI, 2019), however accidents can happen and have (Vattapparamban *et al.,* 2016). Communication can be lost due to geographic position failing to remain connected, or because it has been hacked (Vattapparamban *et al.,* 2016).

4.2.2 UAV Regulations – Civil Aviation Authority (CAA)

There are some ethical concerns also associated with UAVs. UAVs, supposedly, can be hacked, which is a growing concern in the modern age of technology (Goldberg *et al.,* 2013) and this can be considered discouraging in their use and there are different global reactions to using UAVs. For example, in the USA, there are many levels to acquiring permission to fly a UAV legally, which does take time and forms that are required to be completed can use specific jargon that researchers may not be aware of nor use (Vincent *et al.,* 2015). In the UK, the Civil Aviation Authority (CAA) has strict regulations on how and where a UAV can be flown. Foremost, it is the controller’s responsibility to be aware of these rules to remain flying in the Open Category and to keep themselves, property and other people safe, as outlined by the CAA’s *CAP2006* for flying in the countryside (2020a) and *CAP2007* for flying in towns and cities (2020b):

- An online test must be passed to hold a Flyer-ID, and register as a UAV operator and display your operator-ID on your drone
- A UAV cannot be flown above the height of 120 m above ground to avoid accidents with manned aircraft.
- The controller must always keep the UAV in sight to avoid collisions with other.
- There must be 50 m between the UAV and people/property.
- Keep at least 150 m away from parks, industrial, residential and other built-up areas when flying horizontally

- Legal responsibility lies with the controller and can result in criminal prosecution if there is a failure to comply.
- Must not fly in restricted zones – Flight Restriction Zones – of aerodromes, or other restricted airspace.
- Failure to fly responsibly could result in criminal prosecution
- If flying at night, these rules must also be followed

4.2.3 Aerial Imagery with UAV Origins

Using aerial imagery gathered by a UAV is imperative for the data collection requirement of this research. Whilst there are many other data gathering techniques for creating DEMs such as LiDAR, in grassland environments aerial imagery can also be effective at gathering high quality data (Stek, 2016; Federman *et al.,* 2018), and therefore is less expensive to gather. The aim of this investigation is to create a cost-effective framework for analysis, preservation and documentation of earthwork heritage sites using on-board RGB camera on the DJI Phantom 4, without involving other sensors such as LiDAR or thermal imaging sensors, which impact flying times via payload and battery life. This UAV model was appropriate for this investigation for the following reasons:

- A readily available UAV
- Appropriate flight time
- Cost effective
- Interchangeable batteries
- Extra sensors can be added (if required)
- Automated flight path enabled
- Anti-collision software
- Compatible with most mission planning software/applications
- Geotagging feature

Firstly, aerial imagery has been used in other studies; it was used by O’Driscoll (2018), who concluded that this use of aerial imagery, and GIS capable software, was beneficial to mapping and documenting heritage sites in Ireland and Scotland. It was suggested that despite it being a more straightforward technique, it can be deployed effectively in certain environments. When in low vegetated areas, such as grassland, aerial imagery and the aerial photogrammetry process produced DEMs and orthomosaic images that rivalled LiDAR sensors (Bollandsås, 2012; Risbol and Gustavsen, 2018). Susam (2017) used UAV-based aerial imagery for high resolution Digital Surface Models (DSMs) for heritage sites; in that research, it showed that the use of rotary-wing UAVs were useful for low flying applications above archaeological sites, and that the resulting DSMs were effective for analysis of topographical structures of the sites in good detail.

Secondly, the focus was on single sites and not entire landscapes, where UAV aerial imagery and the subsequent analysis may not have performed as well, though Stek (2016) used aerial imagery for site detection in Italy, and that investigation concluded that the technique was highly effective in identifying previously unknown sites in a valley landscape. In single sites, such as a monument or building, Federman *et al.,* (2018) agreed that the use of aerial imagery should not be ignored because it could become vital in tracking and identifying areas of damage to heritage sites and monuments after earthquakes and other natural disasters.

Aerial imagery may be straightforward and it is relatively accurate in regard to georeferencing the photographs on board a UAV, but as Hill (2019) acknowledged, using the geotags that come with aerial photography was not ideal alone; though their investigation suggested for basic DEMs, using the geotags from imagery was acceptable. It could be improved upon through the use of Ground Control Points (GCPs) and handheld GPS units; these can be added into the processing stage to correct the geotags and ensure accurate end products. This was done in this investigation by marking the ‘corners’ of the sites, designated by the investigators, with 1 m by

1 m squares and a handheld GPS unit. These additional geotags were added into the processing stage, which is discussed further in the next section. Kalacska *et al.,* (2020), however, did determine that UAVs capable of geotagging were amongst the most accurate of the UAV platforms when being used without GCPs, and more important than what type of UAV was used, so long as it had the geotagging feature.

4.2.4 The Investigative UAV Flights

Firstly, due to the COVID-19 pandemic and subsequent lockdown, the flight-paths of each site could not be downloaded as access to the drone and flight app was prevented. Therefore, they cannot be added to the appendix of this thesis.

To begin the first stage of this investigation in consideration of the regulations imposed by the UK's CAA, permission was gained from the landowners and/or stakeholders of the heritage sites before a flight could begin, and a day was selected once adequate weather conditions had been ascertained. If the land was used for grazing, the landowner would need to remove the livestock to prevent any accidents involving the UAV and the animals, as expected per the CAA's regulations. At the time of this investigation, livestock was not in the fields.

These sites are open to the public, therefore they were informed that a UAV flight was taking place via several 1-metre-high poles with signs attached alerting them to the flight, that they should take caution whilst visiting, and if there was a problem, to listen to any warnings provided by the controllers of the UAV. Considering that people were more likely to visit on weekends or during school holidays, a weekday was selected for the flights.

A DJI Phantom 4 was used in this investigation, with these parameters as supplied by the company, DJI (2019):

- it is a rotary-wing UAV,
- weighs 1380 g with battery and propellers,

- has a maximum flight time of 27 minutes,
- a maximum speed of 20 m/s,
- an on-board digital camera with an ISO range of 100-1600 for photographs,
- supports micro-SD cards and an electronic shutter speed of 8 – 1/8000 s; and
- uses the GPS/GLONASS satellite positioning systems

Hardin *et al.,* (2019) acknowledged that the 27-28 minute battery life can be variable as it is dependent on altitude, camera power, payload and wind, but swapping out batteries is doable, as the UAV continued its flight from where it left off; indeed, in this investigation several batteries were used. The DJI Phantom 4 is a commercially available UAV, relatively low-cost considering all effective equipment part of it, and this in particular made it viable for this investigation. A DJI Quadcopter UAV, an earlier model, had been used in an investigation of Asinou Church, Cyprus and the resulting 3D model of the church was concluded that having a UAV with an on-board camera is beneficial due to its lack of invasiveness and the high resolution data provided (Themistocleous *et al.,* 2015). The DJI Phantom 4 Pro was also used by Vilbig *et al.,* (2020) in a comparative study with LiDAR and UAV derived photogrammetry on the Cahokia Mounds in the USA, so there is precedence to DJI platforms' functional ability in this type of research.

The next step is to set and plan a UAV flight, and there are apps available for flight path planning and aerial imagery capture. The one used for this investigation was Map Pilot, created by Drones-Made-Easy (2019) as it is designed for use with DJI platforms. There are several highly suitable features within the app:

- Terrain aware features to keep a uniform height above ground
- Easy altitude adjustment
- Overlap management
- Speed management

- Automatic take-off and landing
- Line of sight indicator
- Automatic capture of elevation reference images
- Appropriate camera triggering of up to 1 frame every 2.5 seconds

The ability to adjust the image overlap was imperative, as it provides spatial accuracy (Svensson and Andersson, 2018), as the overlap had to be at least 80 to 90 % to ensure good image coverage of the site. Control of the automatic photograph collection was also a vital requirement, and the app allowed for automatic photograph capture every two seconds, depending on the size of the site. These two particular features were central to the gathering of aerial photographs in this investigation; good overlap and the number of images ensured relatively good accuracy when undergoing alignment in 3D modelling software (Gomez *et al.,* 2015).

Therefore, the DJI Phantom 4 was used for this investigation to gather aerial imagery for this research within the predetermined parameters, which is the preferred data type due to the environment of the heritage sites selected for this investigation; low vegetation areas such as pastures and open field, with no more than heather and bracken present if the site is on moorland, easy access, clear of urban areas and large groups of people. Any visitors will be made aware of the activity during the data collection process.

A flight path was outlined over each site, with a set flying height, overlap and timer for each photograph. This was inputted into the flight control app on an iPad, and the UAV set off on the desired route without direct control from the handler aside from monitoring the flight, be prepared to change batteries when required and to take control should there be an error in flight.

Arbor Low's flight required one stop for a battery change over, but the path went east to west across the henge The UAV height was set to 40 m with an overlap of 80-90%. The Bull Ring's flight was very similar to Arbor Low's in that a single battery change was required, it covered the henge from east to west, and the UAV was set to a height of 40 m with an overlap of 80%. Gib Hill's flight was smaller, the height was set to 40 m with an overlap of 80%, and it followed an east-west route across the fenced off area in which it is situated. Pilsbury Castle, as it was larger, required a larger flight path, and instead followed a north to south line of flight at a height of 70 m as it was the clearer path to take in the flight as the ground rises to the west. Finally, it had an overlap of 90%.

Each batch of imagery numbered over 600 photographs, and these were stored on the on-board SD card reader. Once all sites had been surveyed, the images were downloaded onto a terabyte hard-drive and uploaded into the modelling software.

4.3 Structure-from-Motion and AgiSoft Metashape

4.3.1 Structure-from-Motion

In the processing stage of this investigation, all the aerial imagery collected was removed from the UAV memory card and downloaded onto an external hard drive with enough storage space to begin in the 3D modelling software process on AgiSoft Metashape. This software uses the algorithm Structure-from-Motion (SfM). Structure-from-Motion works by tracking matching features across many images, and it automatically solves geometries, camera positions and orientations without a known network of positions (Westoby *et al.,* 2012; Furukawa and Hernandez, 2015; Aicardi *et al.,* 2018; Nesbit *et al.,* 2018). This factorization algorithm uses data on camera settings and GPS location attached to calculate relative locations of each image and create a sparse point cloud (Tomasi and Kanade, 1992: Ackermann, 2014; Howland *et al.,* 2018). SfM is useful for image processing with nonmetric cameras and low-flying ranges (Colomina and Molina, 2014; Nesbit, *et al.,* 2018). It performs better than Image-Based Modelling (IBM) because the latter does not always recover a complete, detailed and accurate 3D model from imagery (Remondino and El-Hakim, 2006). It is a measurement based from 2D images to recover the 3D shape via mathematical models (Tan, 2014).

Multi-View Stereo (MVS) is a technique that is used within the SfM algorithm (Harwin and Lucieer, 2012); it takes images from viewpoints between two other viewpoints to increase robustness for texture (Furukawa and Hernandez, 2015). Using SfM and MVS combined outdoes other recording methods in cost, detail and accuracy, and are the better methods for high quality 3D modelling using photogrammetry (Hesse, 2015; Sapirstein, 2016; Carvajal *et al.,* 2019); this combination of SfM and MVS offers an efficient, low-cost, rapid framework for remote sensing investigations, which is highly repeatable for remote or inaccessible regions of the world (Clapuyt *et al.,* 2016), and has centimetre resolution which highlights the performance of SfM and MVS (Smith *et al.,* 2016). Conversely, SfM-MVS is flexible, consequently the approach can complicate any attempts to validate SfM-MVS thoroughly as each case utilising it will be different (Smith *et al.,* 2016). Whilst there are commonly differing approaches to using SfM-MVS that prevents attempts to validate the use (Smith *et al.,* 2016), this versatility suggests that many platforms can be used well.

The accuracy of SfM using aerial imagery has been contested, as Hill (2019) suggested that using the geotags attached to each image alone is acceptable for basic collection and processing, but can be improved through the use of terrestrial GPS recordings and GCPs, or the use of Trimble units, though the latter components can be expensive. On the other hand, many acknowledge that SfM-UAVs when used as the only piece of data collection have a good range to them from site-based to landscape-based projects (Campana, 2017, 2020; Akturk and Altunel, 2019). Nikolakopoulous *et al.,* (2017) also proposed that products derived from SfM-UAV techniques have higher accuracy than the classical methods used for photogrammetry. Nesbit, *et al.,* (2018) recommended that using SfM should be as a supplement to traditional techniques in geologic mapping; Koutsoudis *et al.,* (2014) and Green *et al.,* (2014) also agreed that using SfM and 3D modelling should only be used as a supplement to traditional methods. On the other hand, de Reu *et al.,* (2014) disagreed and suggested that 3D modelling has limits that are superseded by the possibilities, and this type of 3D documentation had the chance of becoming a standard technique (Lai and Sordini, 2013).

As a result of SfM's versatility, accuracy and the growing use of this technique is why it was advantageous to use in this investigation: it was focused on single sites, with use of a rotary-wing UAV and the intended outcomes were to produce accurate, high resolution DEMS, orthomosaic images and 3D models. By combining ground control points to correct the geotags attached to each image without having to input or manually calculate known geometries saved time, thereby creating a cost-effective and efficient framework to utilise. This also suggested there was a good chance of repeatability in the use of SfM techniques and aerial photogrammetry.

3.3.2 AgiSoft Metashape

AgiSoft Metashape (AgiSoft LLC, 2019) is frequently used as a modelling software employing SfM to create 3D imagery from aerial photogrammetry. AgiSoft and Pix4D are commercial 3D modelling software, both are capable of using the SfM algorithm to reconstruct a 3D model from aerial photogrammetry, but Agisoft is considered to be have finer resolution rates, and alignment (Przybilla *et al.,* 2019). There are other programmes available for 3D modelling, such as SURE and 3DSurvey (Alidoost and Arefi, 2017). Remondino *et al.,* (2014) held that AgiSoft produced more appealing and reliable results than other 3D modelling software, and whilst it did not produce as many generated points as Pix4D does, its accuracies were similar to that of Pix4D in various land covers (Schwind and Starek, 2017), and Burns and Delparte (2017) agreed that AgiSoft's total error was higher in comparison to Pix4D but its alignment was better.

In an assessment of AgiSoft alongside other software such as MicMac, Keystone and SURE, Niederheiser *et al.,* (2016) created a model of a vegetated rock face, and it was determined that AgiSoft generated points clouds with better accuracy (Niederheiser *et al., ibid*.).

The use of AgiSoft (AgiSoft LLC, 2019) allowed for a direct workflow for alignment, point cloud formation, mesh, texture and 3D model generation (Figure 4.1). It has been used by archaeologists and researchers for heritage objects and sites with many agreeing that the software is an effective tool: Brutto and Meli (2012) compared it to other software with the same intent for 3D modelling, and they determined that AgiSoft was user friendly, in which de Reu *et al.,* (2013) was in agreement. Brutto and Meli (2012) in their research also deemed it cost-effective, accurate and straightforward. Carvajal *et al.,* (2019) also used AgiSoft for virtual reconstruction of cultural heritage for conservation, and agreed that AgiSoft is a low-cost software, is best for close-range projects and is adequate for high precision characterisation.

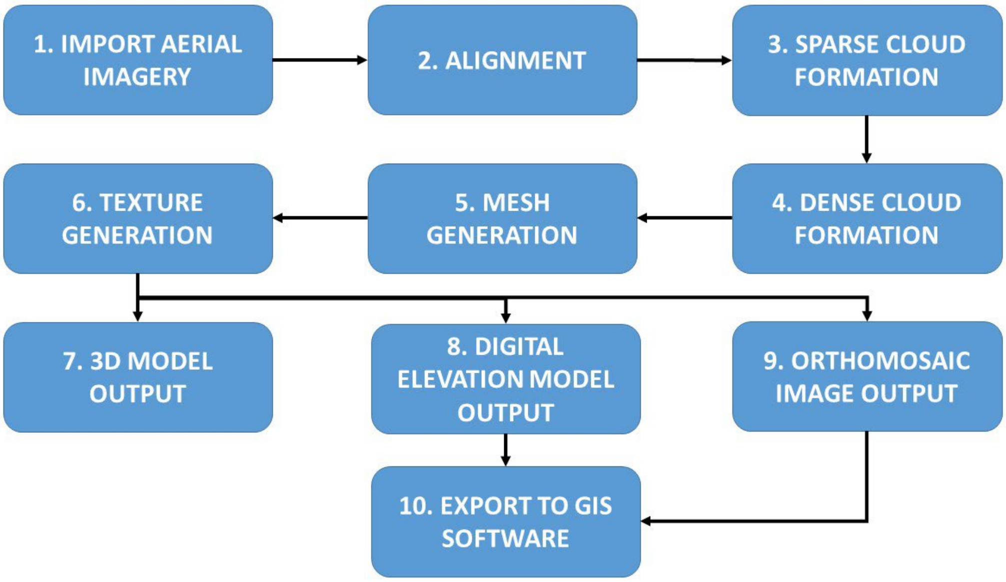


Figure 4.1: A diagram of the workflow in AgiSoft: steps for alignment, DEM and 3D model generation for export to GIS software.

Each image had a set of coordinates and elevation data attached to ensure alignment, but Ground Control Points (GCPs) were added to each corner of the site to be certain the SfM readings were correct (Fonstad *et al.,* 2013; de Reu *et al.,* 2014). By including these GCPs, it resulted in corrected geotags that are gathered with each image, and improved efficiency (Hill, 2019). Quan Li *et al.,* (2016) determined that AgiSoft can quickly produce point clouds in an efficient workflow that produces a high precision 3D model with a low construction time.

There is a key issue associated with the software. Firstly, it requires a sizeable amount of RAM and hard-drive storage, and if highly detailed 3D models are desired, the amount of digital data is considerable (de Reu *et al.,* 2014). When coupled with potentially hundreds of aerial photographs already in storage prior to processing, external hard-drives are preferable storage on desktop computers. De Reu *et al.,* (2013) advocated using a more powerful computer configuration with 8 to 12 GB RAM and a 64-bit operating system with a high-end graphics card to complete the modelling. In this investigation, the desktop computer in use had a 64-bit operating system and 16 GB of RAM installed. The AgiSoft Metashape software was installed on the computer and all products from the data collection was saved to an external hard-drive. The collected imagery was put through the workflow (Figure 4.1) to generate the 3D model, orthomosaic image and DEM, the latter two products for use in the next stage of investigation.

4.4 GIS Procedures

As has been discussed in Chapter 2, GIS has long been used by geographers, but also by archaeologists – it can be seen on the popular UK TV programme *Time Team* (*see Appendix E).* Surveyors on *Time Team* and in other digs, excavations and investigations, frequently used GIS software like ArcGIS in the television show, particularly when displaying resistivity data.

A GIS capable programme has three views: geoprocessing (models), geovisualisation (imagery) and geodatabase (databases); GIS is used for the management, display and analysis of geographic datasets, and has a variety of tools to work with this data (Esri, 2004). Geodatabases are spatial that hold datasets representing geographic data; geovisualisation view is a set of maps that show features and relationships between features on the surface of the earth; and geoprocessing views are the transformative tools used to derive new datasets from existing datasets by applying investigative functions (Esri, 2004).

4.4.1 ArcGIS Pro

GIS is commonly used by researchers studying anything related to geophysical, topographical research and other similar disciplines. It has been evolving over time due to growth in technology that has brought on wider roles for GIS software; once used for data compilation and application tasks, users have since applied comprehensive workstations to compile datasets and workflows (Esri, 2004). As mentioned in a previous chapter, there is a variety of different GIS software available to use in research:

- MapInfo Professional from Pitney Bowes (2019) (licensed)
- Geographic Resources Analysis Support System (GRASS) (2019) (open source)
- Quantum GIS (QGIS, 2019) (open source)
- ArcGIS from Esri (licensed)

GIS can be embedded into web servers and custom applications, and for mobile devices in fieldwork; from this ArcGIS, and all its other components such as ArcMap and ArcScene, was built (Esri, 2004). ArcGIS Pro was the software used in this investigation (Esri, 2019a), and the most recent instalment was ArcGIS Pro. ArcGIS is a regularly used piece of software in academia, and is relatively user-friendly (Osterman, 2014). It is not open source software and it has a costly licence fee. It has many functions in the toolbox that were useful in volume analysis of earthwork heritage sites. Whilst many archaeologists use tools such as *viewshed* (Lock and Pouncett, 2017) because it can inform them of visual presence of a heritage site or monument, this investigation was concerned with volumetric analysis and visualising erosional damage to earthwork features by using other tools inside the GIS such as *slope*, *hillshade*, *raster calculation*, *topo-to-raster* and *natural neighbour*.

There are more visualisation methods available, and Bennett *et al.,* (2012) did a comparison of these different visualisation techniques for heritage landscapes involving *slope*, *aspect*, Principal Component Analysis (PCA), Local Relief Modelling (LRM) and Sky-View-Factor (SVF) using airborne laser scanned data to create them. In Bennett *et al.,* (2012)'s investigation, SVF, LRM and PCA out did *slope* and *aspect* in regard to the number of features recorded, and the complementarity of the investigation showed that no single technique used in their study recorded more than 77% of the total number of features that had already been identified by the National Mapping Programme (NMP), however, all the methods together increased the number of features found by 37%. Features were more easily identified in PCA, SVF, and LRM at a *landscape scale* (Bennett *et al.,* 2012), the methodology of this investigation into damage (erosional or other) could be better highlighted at a site scale using *slope* and *hillshade* before being used inside GIS with other analysis tools. Therefore, when conducted on an easy-to-use platform such as a UAV, monitoring heritage sites could potentially become easier, and could support detailed topographical surveys intended for site monitoring, such as the one done for Arbor Low (McGuire and Smith, 2008).

4.4.2 Stage 1 Common Procedure

In this investigation, three of the four sites underwent a common first stage of analysis – Arbor Low, Bull Ring and Gib Hill - in order to visually present areas of damage to earthwork heritage sites, and a framework was developed for this investigation and split into three stages. The fourth site, Pilsbury Castle, pushed the limits of the methodology as was expected, and had a marginally altered analysis from the third action. The common analysis stage is outlined in Figure 4.2, and subsequently explained in detail.

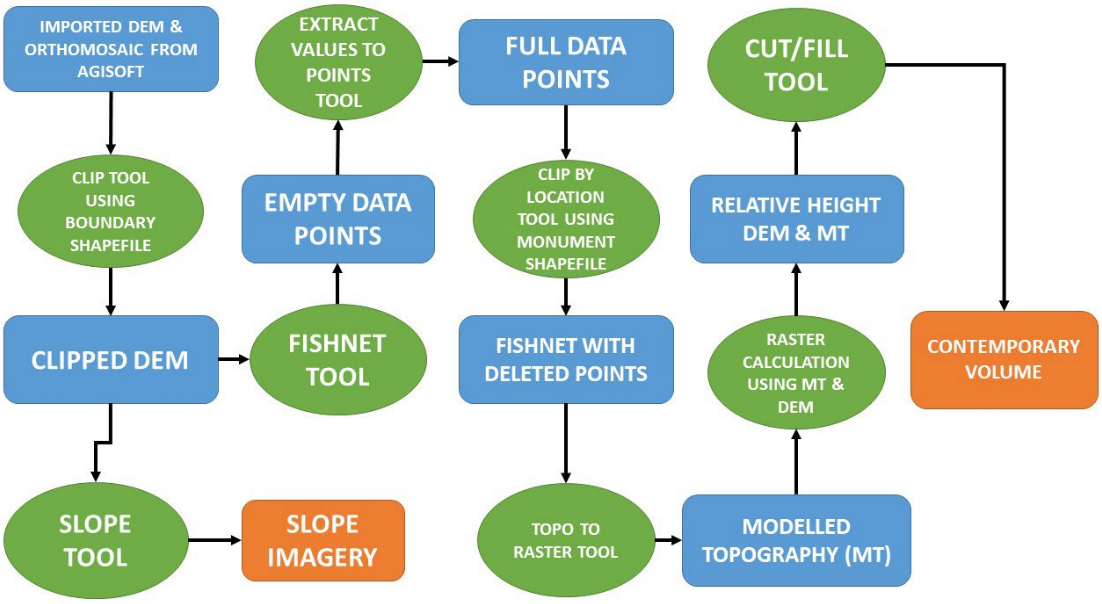


Figure 4.2: First stage of the GIS framework to complete volume calculations of the contemporary earthwork heritage site.

Once the DEM and orthomosaic image created in AgiSoft were imported into GIS software part of ArcGIS (Esri, 2019a), the first tool used was the *clip* tool. *Clip* is used to remove sections of raster layers that are not needed or will impact on the results (Figure 4.3). In this instance, trees, drystone walls, fences and other manmade objects were present in all four sites. The original DEM was not destroyed, instead a new raster layer was created (Esri, 2019b) (Figure 4.2). Two shapefiles were also created: one to cut away the walls or manmade objects [boundary shapefile], and a second one to focus on the monument directly [monument shapefile] (Figure 4.2).

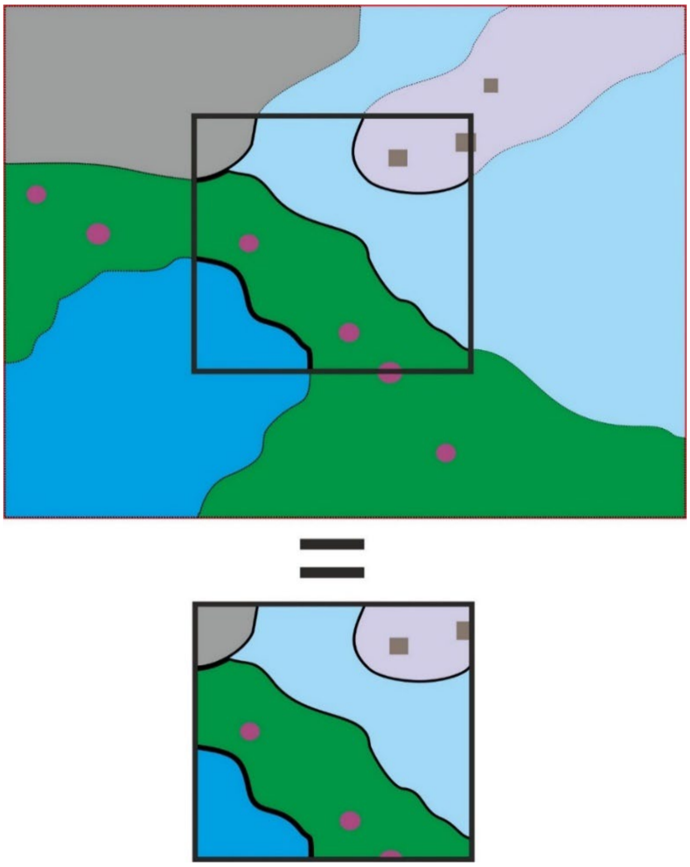


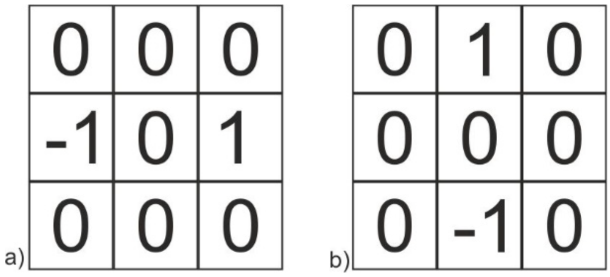
Figure 4.3: How the clip tool works within ArcGIS software, with the central black square representing the shapefile clipping extent, resulting in a new layer of the area of interest (Adapted from Esri, 2019b).

In order to calculate the contemporary volume of the heritage site, a modelled original surface of the landscape in which the site sat was needed (see *Appendix G*). This was to imitate how the land may have appeared prior to construction of the earthwork, and this was achieved by removing height data over the monument - as though it was not there - to form the modelled topography. To begin, a net of cells was generated with a point feature tool called *fishnet*; the grid of empty data points was determined by personal choice, and in this analysis, the specified extent was the DEM, and cell width and height was chosen to be 0.5. The DEM height data was extracted to the data points around the site, and the data points inside the heritage feature were selected using the '*select by location*' tool, this meant any inside the shapefile polygon drawn around the heritage monument were deleted. The remaining points were converted into a raster layer to create a new DEM using '*topo-to-raster'* interpolation tool. This tool works by interpolating elevation for a raster, to create a hydrologically correct DEM that has constraints imposed to remove sinks, therefore made this suitable for idealising an original hillslope or landscape for volume calculations (Childs, 2004).

The clipped contemporary DEM and the new modelled topography needed to be converted from absolute heights to relative heights. This was done to provide easier comprehension of the height change across the site as the analysis progressed and to mitigate any possible issues with data collection, such as errors in height. The height differences would still be the same even if this was completed using absolute heights; relative heights simplified visual understanding. To achieve this, the lowest height of the modern day DEM was taken away from the entirety of both the aforementioned DEM and the newly made modelled topography using the *Raster Calculator* tool. This resulted in new raster layers: the relative height contemporary DEM was at 0 m, and the modelled topography was a negative number. Using the lowest height from the modern DEM meant that both relative height raster layers would essentially be in the same reference plane.

As mentioned previously, *slope* - and *aspect* - are not the first and foremost tools in identifying features within a landscape (Challis *et al.,* 2011b). This investigation wanted to highlight that *slope* was useful for identifying damage to a single heritage site when paired with good resolution imagery. *Slope* and *aspect* are tools in GIS software, and can produce detailed visualisations of damage to earthwork sites. Jones (1998) explained that *slope* is the properties of a plane tangent to a point that is on a surface, and can be specified in terms of a singular normal vector or as both gradient and aspect together. *Slope* works by extracting *x*-gradient and *y*-gradient from a centre cell and eight neighbouring cells (Figure 4.4) – cells being the individual segments that make up the DEM raster. The *X*-gradient determines the slope increase ratio from west to east of the central cell (Figure 4.4a), and the *y*-gradient works south to north (Figure 4.4b).

For example, if the elevation to the west (left) of the centre cell is 100 m and the elevation to the east (right) of the centre cell is 114 m, this means elevation increases by 14 m per two cell widths, giving an *x*-gradient of 7 m per cell width. The *y*-gradient works south-north, therefore if the cell to the south of the centre cell has an elevation of 110 m and the cell to the north of the centre cell has an elevation of 120 m, then per two cell widths there is an increase in 10 m, giving a *y*-gradient of 5 m per cell width (Burrough and McDonnell, 1998; Georgiadou, *et al.,* 2001). The *x*-gradient and *y*-gradient are expressed as '*per cell width'* and is provided in metres (Figure 4.4). The *slope* tool was used to visually present areas of erosional damage that exist earthwork sites today, typically caused by animals, agriculture and tourists. This tool used the contemporary relative height DEM, and the output was measured in degrees.



a)

0	0	0
-1	0	1
0	0	0

b)

0	1	0
0	0	0
0	-1	0

Figure 4.4: a) shows the x-gradient filter west-east (left to right), b) shows the y-gradient filter south-north (bottom to top). (Adapted from Burrough and McDonnell, 1998; Georgiadou et al., 2001).

For the volume calculations, the *Cut/Fill* tool in ArcGIS software summarises the change between two surfaces at a given location, and the results are shown visually as gain, loss, and little to no change (Esri, 2019c) (Figure 4.5), these can be viewed in *Appendix H* and numerically in Chapter 5.

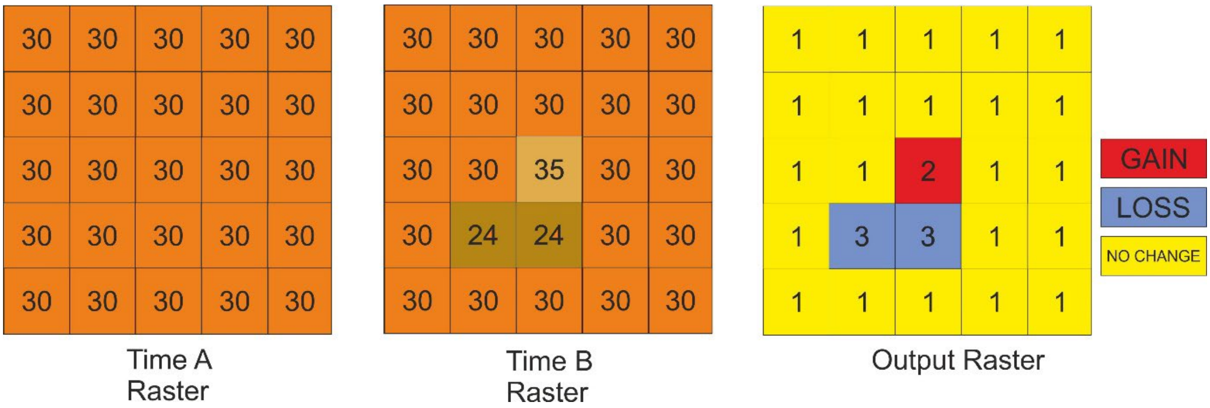


Figure 4.5: How the Cut/Fill tool works by summarising the alterations in surface material at two differing points in time (Adapted from Esri, 2019d).

Once the contemporary volume calculations had been completed, the three sites had altered workflows due to their differing constructions and situations. However, the main commands of the workflows remained, as outlined in the following section.

4.5 Site Specific Procedures

Each site of the investigation had a specific procedure for the volumetric analysis and reconstruction stage of the investigation. Whilst using the same tools in the software, each were applied slightly differently or an additional feature was applied to the site to aid in the rebuilding.

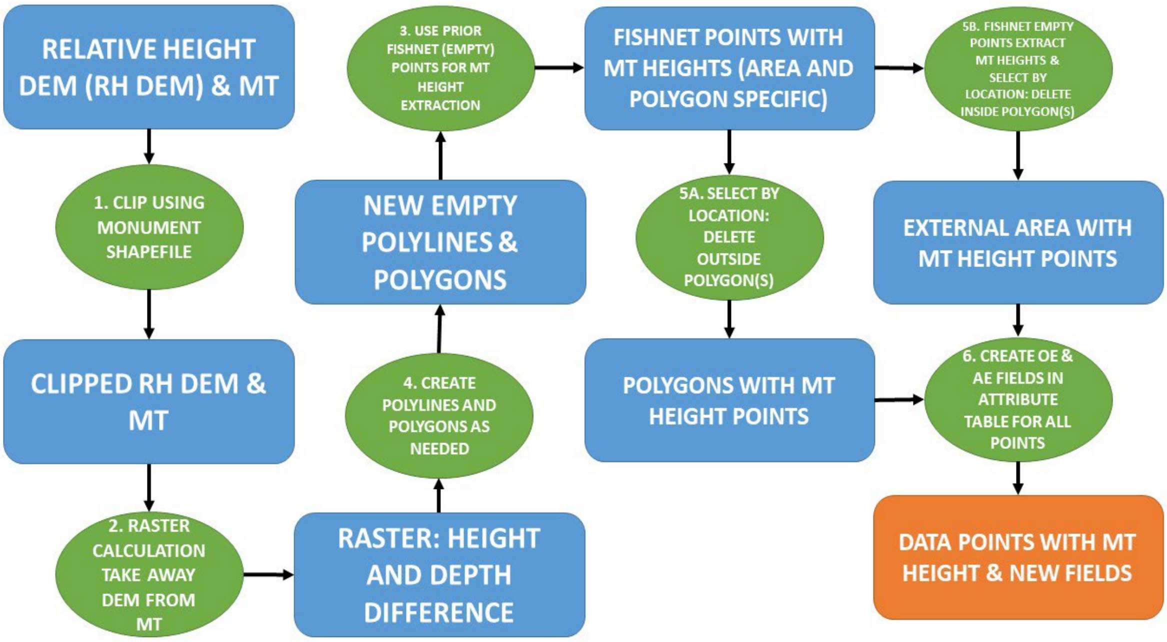


Figure 4.6: Third section workflow of the methodology to create a hypothetical reconstruction of the monument sites, using the relative height DEMs from the second section of the workflow.

For all sites, a procedure was followed using the workflow in Figure 4.6; each marginally different to compensate for the environment or monument type, or because of other features – largely manmade and post-dated of the monument – present in the area; for example buildings present at Bull Ring and fences at Gib Hill.

From there, the data points used in each site, no matter how different, followed the fourth and fifth sections of workflow, though there were minor alterations for the sites due to differences across the sites (Figure 4.7a & b). Pilsbury Castle, only had one section (the hollow-way) focused on, and Gib Hill had several pits to include in the reconstructions and some to remove.

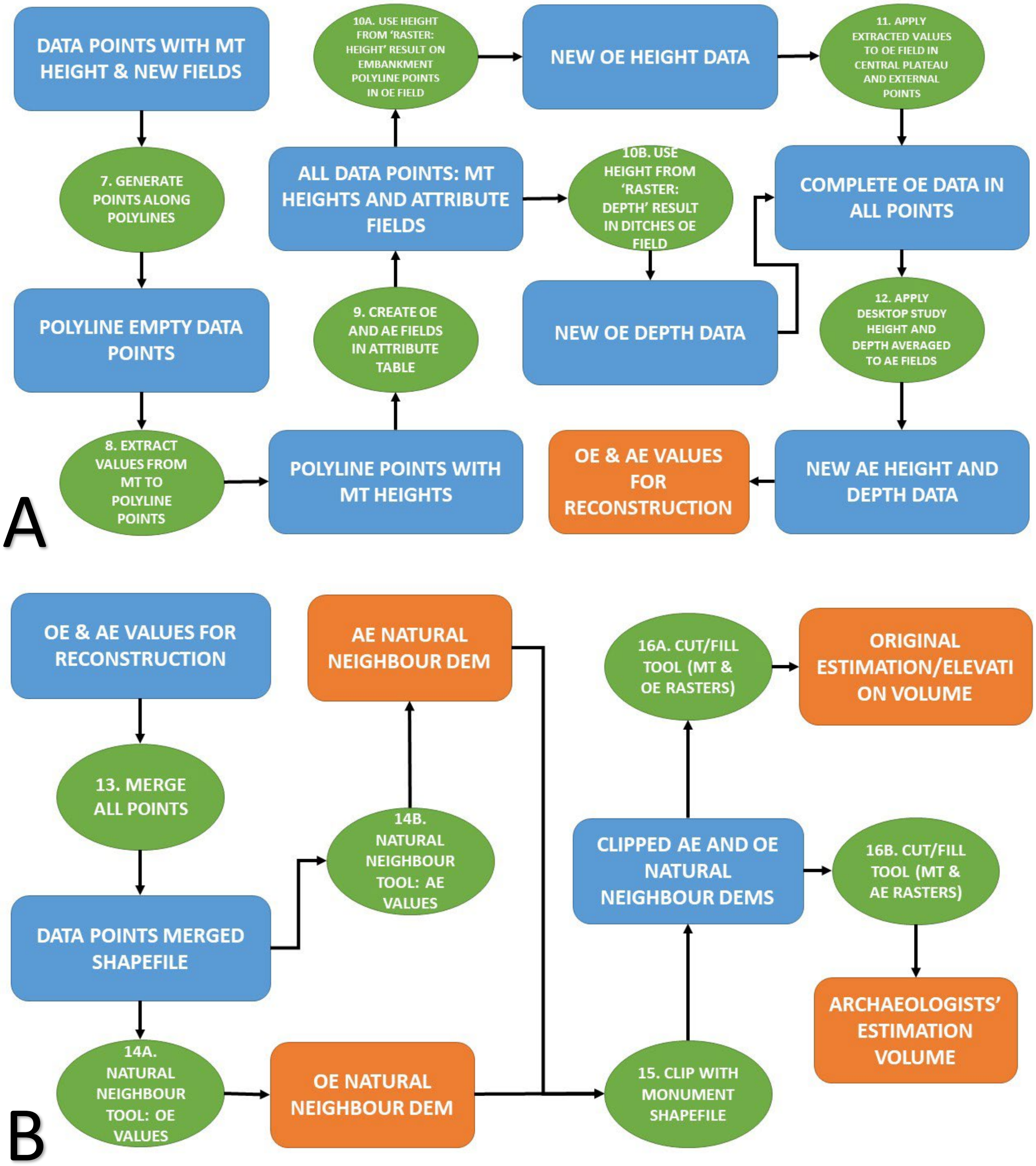


Figure 4.7: Fourth (A) and fifth (B) sections of workflow, with the reconstructions (two or more, site dependent).

4.5.1 Arbor Low and the Avenue

Arbor Low is a type II henge (Rogers, 2013), and resultantly, there is a level of symmetry apparent at the site that played an important part in the sub procedure, as can be seen in Figure 4.8, which displays the diametrically opposing entrances typical of type II henges and outlines where the polygons of the sub procedure lay.

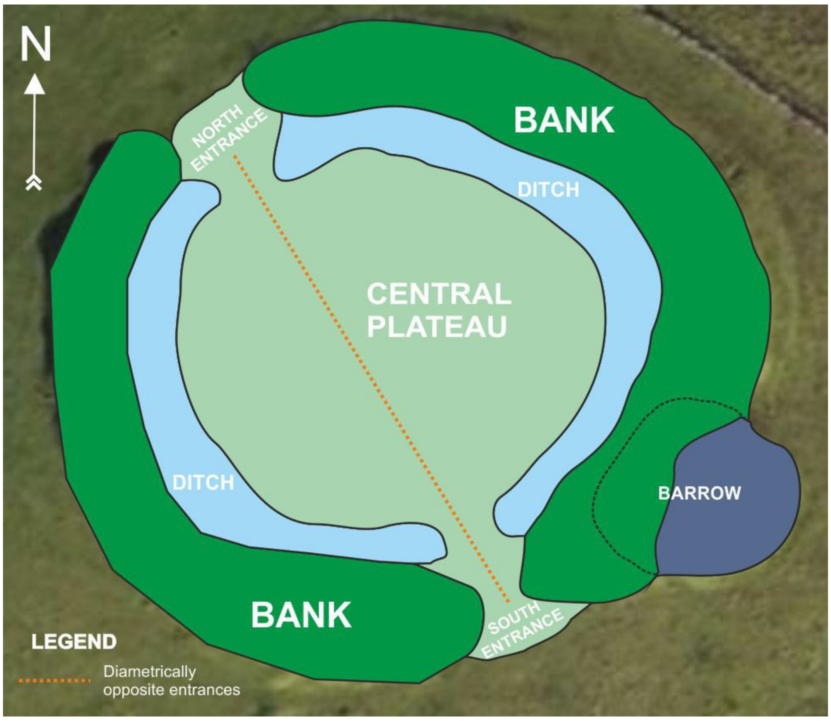


Figure 4.8: Arbor Low is a type II henge, meaning it has two diametrically opposite entrances approximately NW-SE, so there is symmetry applied to the reconstruction (Source: Author's work).

Following the second stage workflow, once the *cut/fill* had been applied to the modern henge, the next step was to determine the highest and lowest points of Arbor Low. The relative height DEM and the modelled topography were clipped using the previously made shapefile that focused on the monument; again this created new raster layers rather than destroying the inputted rasters. This was done to avoid conflict of heights from the wider landscape, as Arbor Low is situated on a false crest on Middleton Moor, which rises above the henge, therefore it would impact the results. By using the *Raster Calculator* tool, one new raster was 'taken away' from another by using Python syntax to perform *Map Algebra* (Esri, 2021). The relative height DEM and modelled topography rasters were taken away from the other; the highest and lowest measurements were provided. These results imply that in the very least, the henge reached this height in the embankments and the barrow, and that the ditches may once have been this deep before siltation and erosion. Despite this, the ditches likely were not a uniform depth as there was no way to accurately determine the true variation due to the passage of time. These measurements – termed '*original elevation'* (OE) – would not be the only measurements used for hypothetical rebuilding; measurements termed '*archaeologists' estimations'* (AE) were also used in a second hypothetical rebuild for comparison and to also visually present a construction that fit what researchers and archaeologists theorised.

Through the creation of more polyline and polygon shapefiles – lines along the tops of the embankments but missing the barrow, a polygon around the central plateau, polygons in the ditches with a gap between them and the central plateau polygon – the empty fishnet points and new points were used. The polyline shapefiles had points generated every 1 m with end points using the '*generate points along lines*' tool. Heights from the modelled topography were extracted to the points. This was also done to the empty fishnet points inside each polygon – once modelled topography heights were extracted, points beyond the polygons (i.e. ditches or central plateau) were deleted as before. The central plateau and ditch polygons have a space between them; this is to enable the creation of steep but not sheer sides into the ditch from the centre of the henge in the rebuild.

Once the heights were extracted, two fields were added to the auto-generated attribute table for the next stage: '*original elevation'* (OE) referring to the original data from this investigation, and '*archaeologists' estimation'* (AE) for previously theorised heights from researchers. The aforementioned highest and lowest points were then utilised. For the central plateau, the modelled topography height was kept the same in both reconstructions, but for the embankments the calculated height result was added to the extracted modelled topography measurement. The lowest depth reading was added to the ditch points.

In the second field (AE) hypothesised heights suggested by researchers were used and added to the data points in the same way as the investigation data, using height and depth specifically suggested for Arbor Low. The archaeologists' estimations were proposed by McGuire and Smith (2008) in their survey of Arbor Low.

For the barrow, two half rings were drawn partway up the front and back of the barrow, ending before the embankments on either side. This was to aid in as smooth a rebuild of the sides as possible. The polylines had points generated along them using the '*randomly generated points*' tool. Again, modelled topography heights were extracted to these points, two additional fields then created in the attribute table as before, and instead of the full height, half of the *original elevation* and *archaeologists' estimation* measurements were added to these data points. Utilising the relative height DEM of the contemporary site, the next polylines were drawn following the current shape as best as possible. A connecting line between the two embankment polylines was drawn in a curve towards the back of the barrow; here the OE and AE heights were added in full to the extracted modelled topography heights. This connecting polyline sat before the partial ring at the back of the barrow.

Finally, the next three full rings the barrow's former pinnacle and points were randomly generated. OE and AE fields were added to the attribute table. For OE, the full result had 0.25 m added each time; therefore, the first ring the new height was 2.77188 m (+0.25 m), until the single top point, where 1.67 m was added to the original OE result. This was because it brought it close to the 4 m suggested by researchers. Therefore, for the AE rebuild, in order to have the single point at the top reach 4 m, but for the three wings to build smoothly, 0.2 m was added to the 3 m AE result.

The last feature of the area was the Avenue – a feature perhaps younger than the henge – and may once have been a field border of ancient fields in the Roman or Anglo Saxon periods. Fishnet points within the avenue's shapefile polygon were deleted, as before, and points were generated every 0.5 m with end points and modelled topography heights were extracted to them. Another *raster calculation* was done for this feature following the same method as for the henge – using a polygon shapefile, the relative height DEM and modelled topography were clipped to fit and then one taken away from the other to produce an OE result of 0.653809 m. The AE measurement was given as 1 m by McGuire and Smith (2008).

For the reconstructions, the data points are joined together with the '*merge'* tool, and then interpolated using the '*natural neighbour*' tool. Two new DEMs/models were made: one using OE data and the other using AE. It was hoped that the rebuilds would imitate an artist's interpretation of how the henge once looked (Figure 4.9a), which is available on signage at the site in the Peak District (Figure 4.9a) compared to a contemporary Arbor Low (Figure 4.9b).

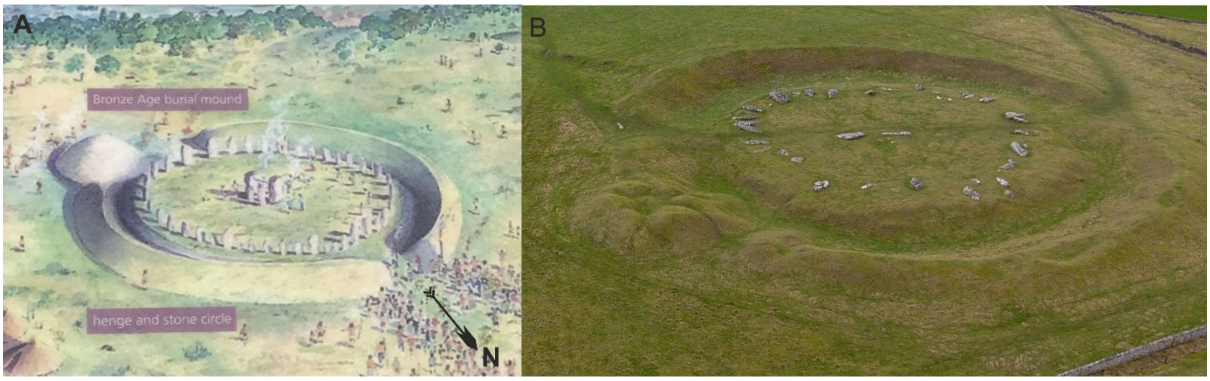


Figure 4.9: A) an artistic interpretation of how the earthwork site Arbor Low may have looked when first built in the 3rd millennium BC E (Source: Artist unknown, in Barnatt and Smith, 2004). B) This is an aerial view of the present day Arbor Low (Source: H Malbon/Alex Nobajas, 2020).

The reconstructions of Arbor Low, as it is with all of the sites, are hypothetical. The volumetric data gathered from the two reconstructions are simply reflections of the hypothetical nature of the rebuilds. They are not intended as absolute truth, but simply a presentation of what could have been, prior to any type of human action (direct or indirect) that has led to damage in the present day.

For the hypothesised volumetric results, the *cut/fill* tool was used once again on both the OE and AE reconstructions, using the modelled topography with them. The results varied and were compared with the modern volume results in order to see the differences between the contemporary henge and the two potential original states.

4.5.2 Bull Ring

The Bull Ring is comparable to Arbor Low; indeed, it has been theorised that the same people built both of these henges (McGuire and Smith, 2008). This meant that it could be supposed that there was a level similarity in height and width to Arbor Low. This aided in the reconstruction attempt for the Bull Ring, however, there was far more damage accrued at the site; in fact, it is in a recreational field and was once under threat of complete destruction in the 20th century from quarrying (Tristram, 1915), and unlike Arbor Low, there was no signage at Bull Ring to suggest how it may once have appeared.

After completion of the shared procedure, Bull Ring followed a similar workflow to Arbor Low due to being a henge monument. However, within the central plateau at Bull Ring, there was a small tree that interfered with the height determining *raster calculation* after creation of the modelled topography. Subsequently, individual pixels that formed the tree had to be altered to match pixels around it. The following equation was used in the *raster calculator:*

$$Con((pixel >= Raster\ X) \& (RasterX >= altered\ pixel), smaller\ pixel, RasterX)$$

This was done carefully, as eventually the pixel heights of the tree came close to the pixel heights of segments in the embankments. This was because despite the pixel heights being almost individual, there was always the chance that another pixel elsewhere would match, and also be altered by the equation as it would fall into the desired parameters. The tree did sit within a particular height range, so wider parameters were used to remove a large portion of the tree, replaced with a nearby pixel height in the central plateau. The remaining tree pixels were removed individually using the same equation but with minute parameters.

Once completed, the new raster had an appropriate height difference for the embankments to be used as OE results. Again, due to the level of damage at Bull Ring, there was every chance that the ditch measurement was impacted – on the north-eastern side of the plateau, there was a concave area caused by small scale quarrying in the 20th century – and gave a deeper measurement that what would have been likely.

Shapefiles were similar to those at Arbor Low: one designated for the central plateau, two for the embankments and two for the ditches. However, whilst there is a barrow at Bull Ring, it sits apart from the henge and is not part of the embankment, so it was not included with the final rebuild. The final difference was the presence of a berm as outlined by Barnatt and Myers (1988) on the south-eastern side of the henge, between the embankment and the ditch. It was only observable here, but theorised to follow around to the north-eastern side and even mirrored on the western embankment. Therefore, a new shapefile was applied to this area.

Heights were extracted from the modelled topography to the fishnet points, and deleted as needed for the particular sections. Two polylines were drawn along the tops of the embankments, and points were generated every 1 m with end points, and heights were extracted to these. As before, these OE measurements were added to the points, aside from the central plateau and the berm – OE and AE fields equalled the same as the modelled topography height extracted.

Determining the north-eastern extent of the central plateau was a harder to establish than at Arbor Low, due to the extent of damage over its history, including the quarrying at the edge of the plateau and also on the opposing embankment. This impacted understanding where the berm lay to determine the shapefile placement, however there was enough visible that an acceptable determination was made.

These points, including an OE and AE value using the modelled topography heights for around the henge, were merged and two DEMs were created using '*natural neighbour*'. As before, these are hypothetical rebuilds of the henge and should be remembered to be so. Once the DEMs were constructed, the volumetric calculation was done with the '*cut/fill*' tool for the OE rebuild and the AE rebuild, and finally compared with the contemporary data.

4.5.3 Gib Hill

Gib Hill is not a henge like Arbor Low and Bull Ring. It is two barrows – an original long barrow that predates even Arbor Low as the main feature on the moor, and a younger superimposed round barrow on the south-western end of the long barrow – and this meant that establishing shapefiles placement was different. The older long barrow is no longer as clearly defined, and the south-west end is under the superimposed round barrow, therefore they were distinguished in order to appropriately reconstruct both.

Following the common stage, an archaeological survey plan done by John Barnatt was georeferenced onto the aerial imagery (see *Appendix D*). This was to aid in determining which features belonged to each barrow. There were several ditches or pits surrounding the feature on the south-south-eastern side around to the north-western side, all of different ages and were either associated with a particular barrow or even a period following construction completely.

Firstly, the round barrow features were distinguished. The older long barrow was present when the round barrow was built, so a shapefile dedicated to the feature followed the extending north-eastwards and ended on the northern side of the round barrow where they meet. The fishnet points had heights extracted from the contemporary relative height DEM, as the long barrow was likely a little higher during construction of the round barrow, it cannot be determined how much had or had not been lost at that time. The *raster calculation* was then completed as with the other sites for an OE result.

Two types of pit were identified by John Barnatt as being associated with the building of the round barrow. They had depths of between 0.1 and 0.3 m (Barnatt, in McGuire and Smith, 2008). Another type of pit was associated with post barrow quarrying, and a final type of pit was associated with construction of the long barrow. Each type had an associated shapefile outlining them, with a description of which barrow they connect to. A berm also existed on the southern end of the barrow, and a shapefile outlined the extent of it by following the archaeological survey as it was somewhat difficult to identify on the aerial imagery correctly.

For the rebuild of the barrow, several rings of shapefiles were created, shrinking as they climbed to the top of the barrow. However, unlike the round barrow at Arbor Low, this does not have a single point at the top, but a small ring. Each shapefile had points generated every 1 m with end points. Writing by William Bateman in 1824 suggested 18 ft. or 5.5 m, though in a survey done in the late 1980s (Barnatt, 1989a) theorised this may have been too high. However, it was used to show the difference.

Modelled topography heights were extracted to the points along the rings, to the fishnet within the pit shapefiles, and around the feature. Aside from the latter points, which remained as the modelled topography heights, the OE and AE measurements were divided by the number of rings in order to build carefully and in-shape with the barrow. Only the ring at the top altered this and had 10 % of the OE and AE measurements added on to the full OE and AE result.

For the long barrow, a second *raster calculation* was completed, but this only included the long barrow up to the round barrow, to determine an OE solely of the older barrow. This was because the remaining height was needed for the long barrow, and the calculation for the round barrow would not have been acceptable. Points inside the round barrow shapefile were deleted from the fishnet points after the relative height DEM values were extracted to them. From there, using the '*topo to raster´* tool, a DEM was created without the round barrow, but kept the long barrow. This was then used inside the *raster calculation* tool with the modelled topography and produced an OE result.

By creating the shapefile around the round barrow meant that the join where the long barrow met it could be used as an appropriate high point of what remains of the long barrow today. Three rings of shapefile polylines were created, and points were generated along them every 1 m with end points, and the modelled topography heights were extracted. Points around the wider long barrow shapefile were also used again, and only one identified type of pit was associated with the long barrow construction. The rest were not included in the merging

Once these had their values extracted, three rebuilds were created: one OE rebuild and two AE rebuilds. This was because Barnatt (1989a) suggested the barrow was no more than 1 m high, but Historic England (2022b) gave 2 m. Again, for the elongated loops, the suggested heights were divided by the total number of them, and the final ring received an extra 10 % of the OE and AE heights. It so happened that the OE produced height from this investigation lay between the two heights from researchers.

4.5.4 Pilsbury Castle

Pilsbury Castle was a very different and complex site. Of the four, it was the largest and the castle made use of an already present headland (Landon *et al.,* 2006) which subsequently pushed the boundaries of the methodology and intent of this investigation. Unlike the other sites there were many trees present at Pilsbury, particularly down to the river and the south-western side of the earthworks, but there was also a mature tree on the eastern bailey at the foot of the knoll. Whilst some were removed in AgiSoft software, others were either far smaller or sat below dips and lifts of the castle, meaning pieces of the castle itself would have been removed.

Regardless, relative height was still established by taking the lowest height away from the DEM to create a new relative height DEM. The '*slope*' tool was also used and it highlighted pathways across the field and features of the castle, as well as up to the limestone knoll. However, due to the complex nature of the site, careful consideration had to go into determining how, if possible, to create a modelled topography in order to attempt volume calculations. Firstly, the limestone reef knoll on the eastern bailey was there prior to the construction of the castle; at most material may have been piled at or around the base during construction of the eastern bailey. Secondly, the motte was raised by material removed from the hollow-ways that surrounded it, separating it from both baileys (Landon *et al.,* 2006). Consequently, this meant that symmetry did not work like it did for Arbor Low, Bull Ring, and to an extent at Gib Hill. Pilsbury was also constructed on natural headland (Landon *et al., ibid.*), therefore creating a modelled topography was harder to determine.

However, since it was theorised that the hollow-ways were likely either deepened if not constructed fully by the builders of the castle, this meant this smaller alteration could be measured. Instead of a modelled topography of the entire site, a localised one for the hollow-way separating the eastern bailey from the motte was generated. This was done by creating polygon drawn to follow the contemporary contours on the eastern bailey from its highest elevation closest to the motte; in this case the relative height DEM showed 27 m to be the last shared height on both eastern bailey and motte. A fishnet of points was created the same as the other sites, removed from over the river and over any trees present at the site. The fishnet points had height data from the relative height DEM extracted to them, and points sitting outside the polygon were deleted. A second polygon shapefile was created, this time to create a buffer zone on each end of the first polygon, as this was to allow for a smoother transition in the interpolation from the external points to the internal points. No fishnet points sat inside the buffer zones to aid in this.

From there, the points were put through the *natural neighbour* interpolation tool and not *topo-to-raster* as the entire contemporary site was also built up around the altered hollow-way. This modelled topography therefore was a recreation of the entire modern-day site with a ‘filled in’ hollow-way. In order to focus on the altered area, a smaller *clip* polygon shapefile marked from the end of the eastern bailey to the motte and covering the hollow-way, was used on both the relative height DEM and the modelled topography. The localised relative height DEM and modelled topography were then used with *cut/fill* to determine an estimated volume measurement.

4.6 3D Printed Models

Finally, once all the models had been completed, the last step was to choose a select few to create a 3D printed model. As was argued in previous chapters and the part of the intent of this investigation, 3D models can be used within the documentation and the dissemination of information to the public in the forms of physical and interactive museum or heritage centre exhibits.

To do this, the contemporary DEM and the reconstructed sites files were opened inside the 3D printer software, *Cura* (Ultimaker, 2022a), and prepared for printing. Depending on printer size, the models could be scaled down (or up) as needed. Once an appropriate size was achieved, the file was sent to the printer to print a 3D model of the site; in this investigation the 3D printer *Ultimaker 2+ Connect* (Ultimaker, 2022b) was used.

Cura is made by the Ultimaker Company alongside the 3D printer used in this investigation; Ultimaker Cura is free to download from the Ultimaker website and considered the world's most popular 3D printing software (Ultimaker, 2022a). The Ultimaker 2+ Connect was a versatile 3D printer with a single extrusion with changeable nozzles, cloud-enabled remote printing, can print with nine different materials, and had a build volume of 223 x 220 x 205 mm (Ultimaker, 2022b). This made it a very suitable printer for the printing of well sized models of the sites in the investigation.

The specialised plastic or resin used for printing could be either green or grey, and the average length of time to print each site would likely be over 24 hours, but longer still for the larger site of Pilsbury Castle. Once completed, the newly printed models would be evidence of the possibility of using 3D printed models in the public sphere to educate and bring them in to atmosphere of seeing a contemporary reconstruction of a heritage site using real-life data in the form a DEM.

4.7 Conclusions

Everything about the methodology was to rebuild hypothetical reconstructions of these four sites. There is no definite way to know just how these structures appeared when first built, and there is concern in the archaeology community about such attempts as rebuilding and 2.5D modelling. However, these sites would benefit from such a multidisciplinary backing as the preservation and documentation of these sites is imperative in their continued survival and to pass on knowledge for future generations. As technology evolves, so too shall the methodologies and practices of remote sensing, aerial imagery and GIS.

It is also a cost effective way for NGOs such as the Peak District National Park Authority to monitor their earthwork heritage sites through the use of GIS and UAV aerial imagery for damage and protection, as well as to document sites that are almost completely destroyed or under threat.

Chapter 5 Volumetric Analysis and Virtual Reconstruction

5.1 Introduction

This chapter outlines the results, both numerical and imagery based, of this investigation and site specific discussions of the results. There are several visualisations for Arbor Low, Bull Ring and Gib Hill, with a minimum of three volumetric results: one for the contemporary site, and at least two more for the theoretical reconstructions. However, due to the complex nature of Pilsbury, only one volumetric result was calculated for the site. Each site has several sets of results, both volumetric and imagery based; firstly, the contemporary site is visualised in oblique photography, in GIS software, before the second section covers the volumetric analysis, followed finally by the third section covering the virtual reconstructions, but also see *Appendix H* for the images produced from the cut/fills. The reconstructions and the relative height DEMs can be viewed as 3D imagery with the contemporary orthomosaic image texture in *Appendix F*.

5.2 Arbor Low

Arbor Low had three different visualisations using oblique aerial images, the *slope* and *hillshade* outputs were created in order to display damage at the site, and pathways commonly used, which are of concern to the continued health of the site. These visualisations offer different levels of detail in displaying these areas of concern, which are the focus of the next step.

Secondly, a volumetric analysis was completed for the contemporary site using data derived from the UAV aerial imagery. This was to be used in comparison with the virtual rebuilds that utilised primary data sourced from the aerial imagery and termed *Original Elevation (OE)*; it was termed thusly because the height data extrapolated from the drone aerial imagery into a DEM used the highest remnant height on the monument for the rebuild and from secondary resources, termed *Archaeologists' Estimation (AE)*. However, both rebuilds (OE and AE) used archaeologists' estimations of feature widths, such as the ditches at Arbor Low. In both rebuilds, the ditches at Arbor Low are as close to width estimations from archaeologists as well.

These rebuilds were the penultimate step in the investigation. Using both OE and AE data, they are the final visualisation but not of a present day Arbor Low, but of a theoretical rebuild of the monument in it's past; perhaps following completion or following alteration and was left. The digital nature of these models does mean they can be utilised further which will be discussed in Chapter 6.

5.2.1 Visualising the Contemporary Monument: Arbor Low & the Avenue

Firstly, oblique aerial imagery and the first stage visualisations were used to highlight any damage present and other areas of concern at each site. This was to clearly establish where reparative or protective efforts should be focused by the relevant organisations that care for the sites. At Arbor Low, the aerial images (oblique and bird's-eye) clearly show areas of interest and can be identified, such as on the barrow and the embankments (Figure 5.1a), and the cut-through on the avenue (Figure 5.1b).

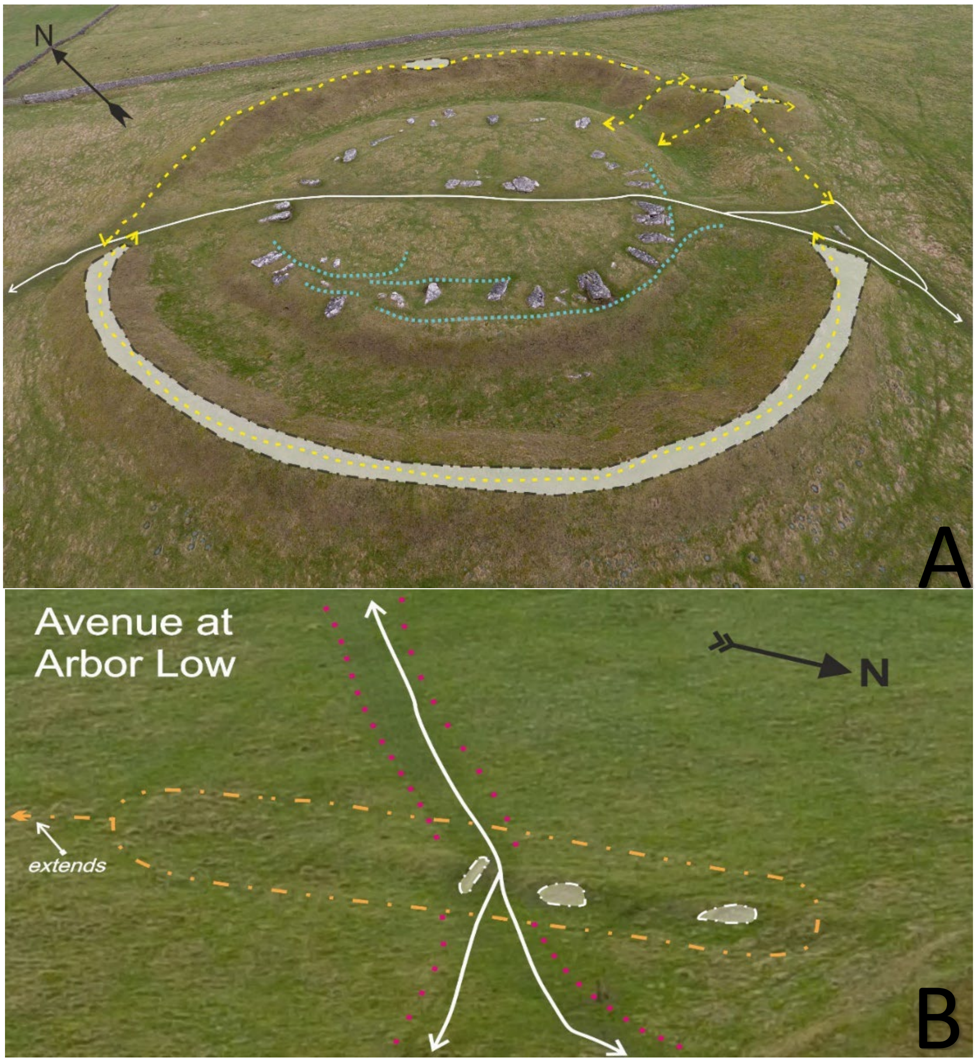


Figure 5.1: (A) Oblique aerial image of Arbor Low. Pathways highlighted in white, yellow and blue show tracks left by people or animals, and then areas of damage or flattening (pale regions). (B) Oblique of the avenue (orange), pale areas depict damage, and dashed pink lines mark the pathway; it extends to the left of the image, but is beyond the drone imagery.

The areas of concern demonstrated in Figure 5.1 are echoed clearly in Figure 5.2, particularly in the barrow and across the eastern embankment. The damage to the barrow was caused by improper backfilling by Thomas Bateman in his 1840s excavation; he left the crater and five knolls about the top (Thompson, 1963). In regards to the embankment, this investigation suggests that the increased erosion on the eastern embankment is due to visitors at the site or livestock when they are out in the fields. In Figure 5.1a, scratchings caused by livestock are demarcated (blue lines), and spots around the orthostats, and are not comparably as concerning as other damaged sections, but McGuire and Smith (2008) noted them before repair works went ahead soon after.

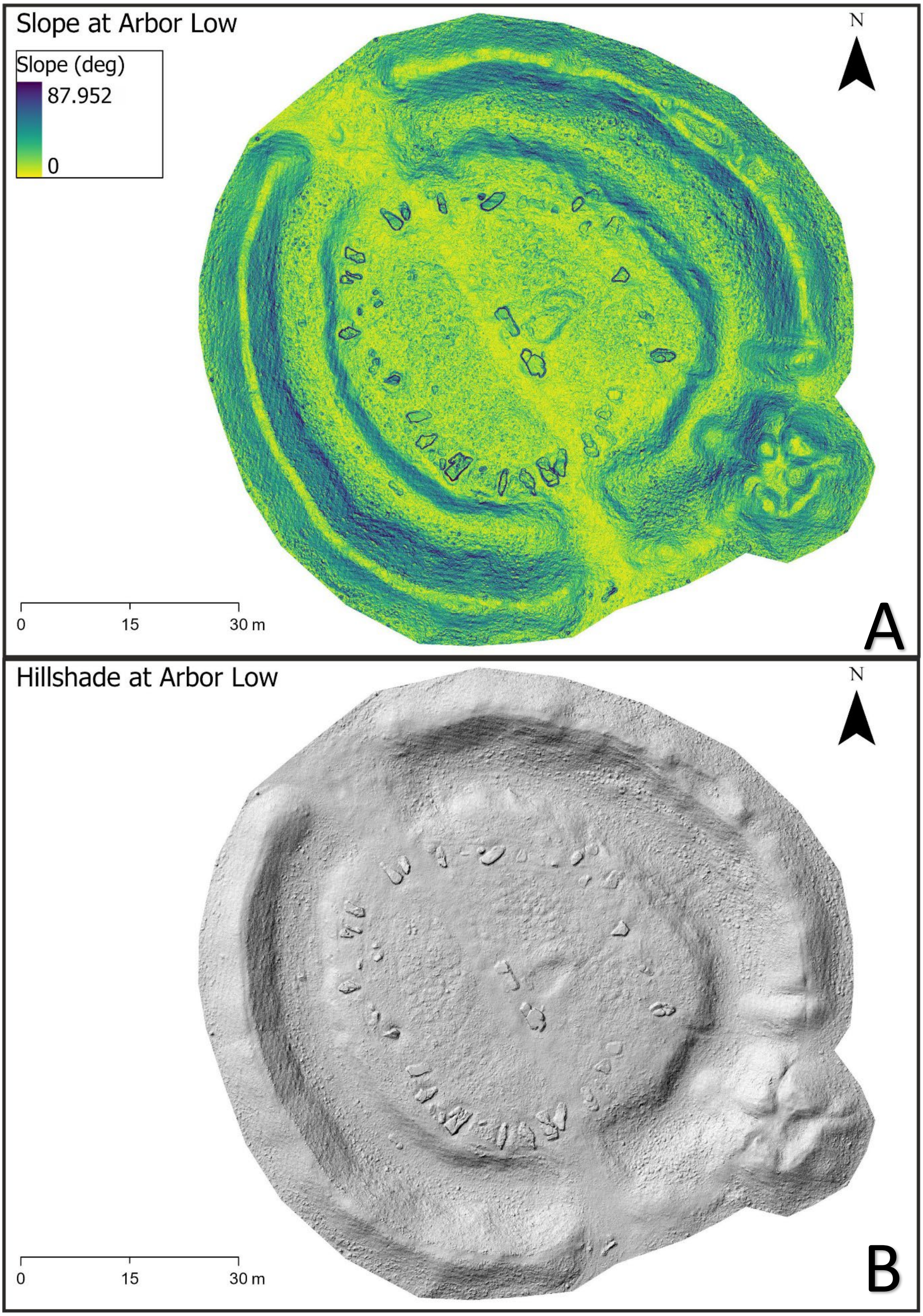


Figure 5.2: A) The slope tool highlighted areas of concern at Arbor Low; everything determined to be at low angles that likely should not – such as across the tops of the embankments and in the barrow – are visible in this visualisation. B) Hillshade of Arbor Low. As it does not give absolute elevation measurements, it works as another visualisation of damage at the contemporary site.

The *hillshade* tool is another visualisation tool that also highlights the areas of damage in a similar way to the *slope* tool, except there are no precise elevation values. It uses positioning of the sun via azimuth and altitude (Figure 5.2b).

The additional feature at Arbor Low, termed the Avenue, predates the henge and was theorised to be an ancient field boundary (McGuire and Smith, 2008). Due to the damage, it was decided the avenue was of interest, and the *cut/fill* tool was applied to the feature (Table 5.1) and the modelled topography was clipped with an avenue shapefile. Since it is an uncertainly clarified feature, the rebuilds are very theoretical (Figure 5.3).

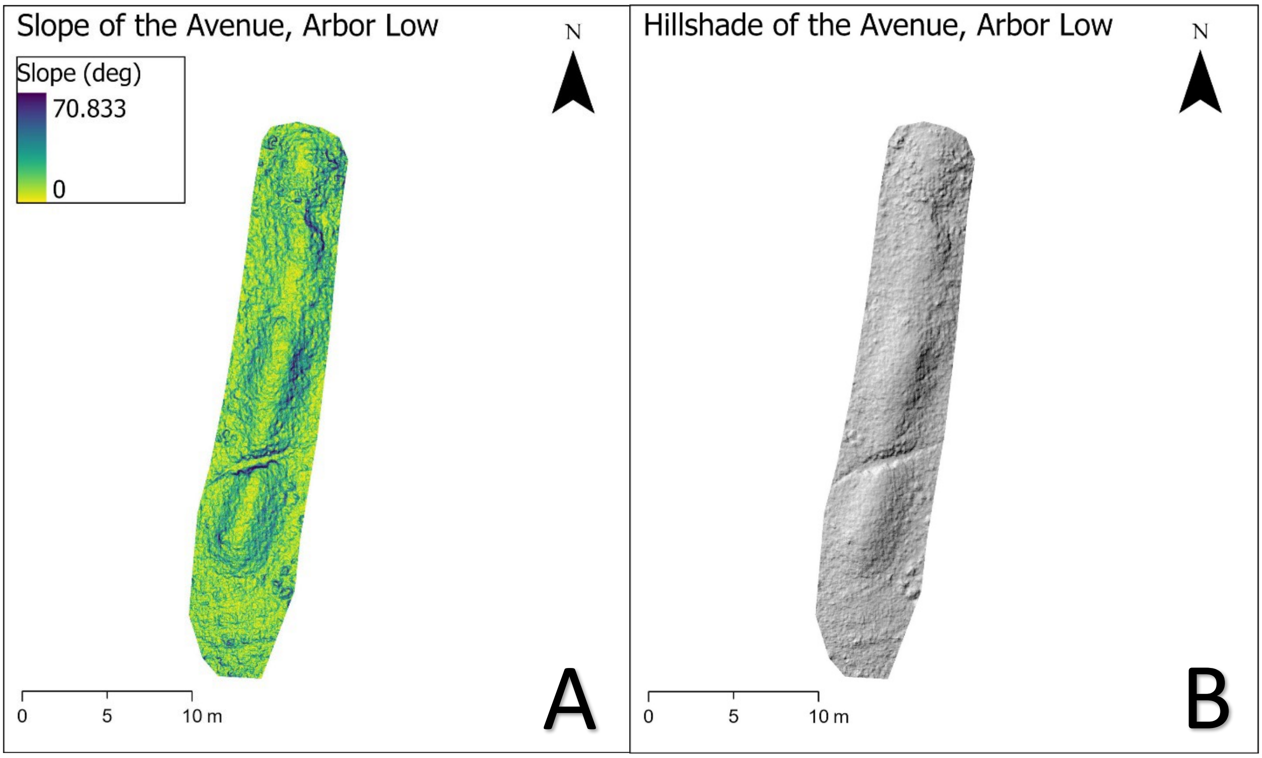


Figure 5.3: Slope (A) of the avenue clearly demarcates where a pathway cuts through the avenue, as well as damage to the NE side. Hillshade (B) also marks the same, though not so sharply.

For Arbor Low and the associated Avenue the visualisations make plain the damage on the embankments and barrow. Whilst the damage on the barrow originated from a William Bateman excavation in the 19th century (Thompson, 1963), damage elsewhere is most likely derived from agriculture activity, such as on the Avenue. Though as explained in Chapter 2, this site has been relatively protected indirectly by its location compared to similar sites such as the Bull Ring, and gaps exists in the timeline of the site. Thompson (1963) acknowledged that visitors had started coming to the site during the 1960s so this can be interpreted that the public has visited for the last sixty years. Desire paths have appeared across the site (Figure 5.1), and this has every chance of being exacerbated as visitors frequent the site, particularly if this has increased during the COVID-19 pandemic.

5.2.2 Volumetric Results of Arbor Low: Contemporary and Reconstructed

For the contemporary Arbor Low, the first set of volumetric data was calculated. Firstly, the *cut/fill* tool was applied to the contemporary DEM to get a result for the henge as it appeared in February 2020, using the modelled topography as the base, as explained in Chapter 3, and summarised here:

- Create a modelled topography of the landscape prior to *any* construction
- Apply the *raster calculation* tool to the contemporary site and modelled topography for the first rebuild
- Establish the prior archaeologically derived measurements for the second rebuild

After completing that stage of the methodology, the reconstructions made and analysed, the differences are clear (Table 5.1), but form a basis of understanding and a start point for monitoring the monument.

Table 5.1: The determination of heights and depths to be used for reconstruction. OE determined by a raster calculation and AE by researchers, in this case McGuire and Smith (2008).

ARBOR LOW – OE AND AE HEIGHT/DEPTH (metres)

RASTER CALCULATION/ ARCHAEOLOGICAL ESTIMATE	**EMBANKMENTS**	**DITCHES**	**BARROW**	**AVENUE**
ORIGINAL ELEVATION DEM	2.27	-2.045	2.27 + *0.25 increments up to c. 4 + 10 % added*	0.653
ARCHAEOLOGISTS' ESTIMATION DEM	3	-2.5 (avg.)	4 (*incremental)*	1
DIFFERENCE	0.73	0.455	-	0.347

As Table 5.1 demonstrates, the application of *cut/fill* on the contemporary site to provide OE derived measurements do fall within or below what is estimated by researchers for the site. McGuire and Smith (2008) noted the Avenue was less than a metre high at the time of their survey, so 1 m was used as the AE height. These differences led to the differences in volumetric analysis (Table 5.2). These will be discussed in the next section.

Table 5.2: The results of the cut/fills for all three DEMs; the contemporary site, the OE rebuild and the AE rebuild, to demonstrate the variances between the 'theoretical then' and now.

ARBOR LOW CUT/FILL VOLUME (cubic metres)

MODEL	**EMBANKMENTS (incl. BARROW)**	**DITCHES**	**CENTRAL PLATEAU**	**AVENUE**
2020 DEM	2039.978	-1985.922	174.866	36.596
ORIGINAL ELEVATION DEM	2745.771	-2901.380	-	60.189
ARCHAEOLOGISTS' ESTIMATION DEM	3584.684	-3519.623	-	92.114
Difference OE/2020	705.793	-915.458	-	23.593
Difference AE/2020	1544.706	-1533.701	-	55.518

5.2.3 The Virtual Reconstructions of Arbor Low

With both the relative height and idealised topography generated, *cut/fill* was applied in order to determine the volumetric data for the site. Again, it must be remembered that this height and depth derived from the raster calculation is to be called theoretical, as is the rebuilds using prior researchers' theories.

The data tables can be seen in Section *5.2.2*, and as is shown specifically in Table 5.1, there is a difference of 0.73 m in the height derived from the investigation and what researchers have posited in prior surveys. There is, also, only less than half a metre difference between the theoreised measurement from researchers and the remnant height from the aerial imagery. Researchers did give a varying depth for the ditches as the bases were unlikely to have been a uniform depth at any time in history; however, this is difficult to implement effectively or appropriately in a digital constructed feature. Consequently, an average was used and this meant the OE depth would fall within researchers' estimations, but when averaged it results in a difference of 0.455 m.

Four reconstructions were made – two of the henge and two of the avenue – that were combined into two: an OE reconstruction of the henge and the avenue, and an AE reconstruction for the henge and avenue. The first reconstruction was the OE rebuild, using the aforementioned given heights in *Section 5.2.2*. The visualisations of the OE rebuild can be seen in Figure 5.4a and 5.4b, as a wider site model and a focused model of the avenue, due to its smaller size in comparison to the henge.

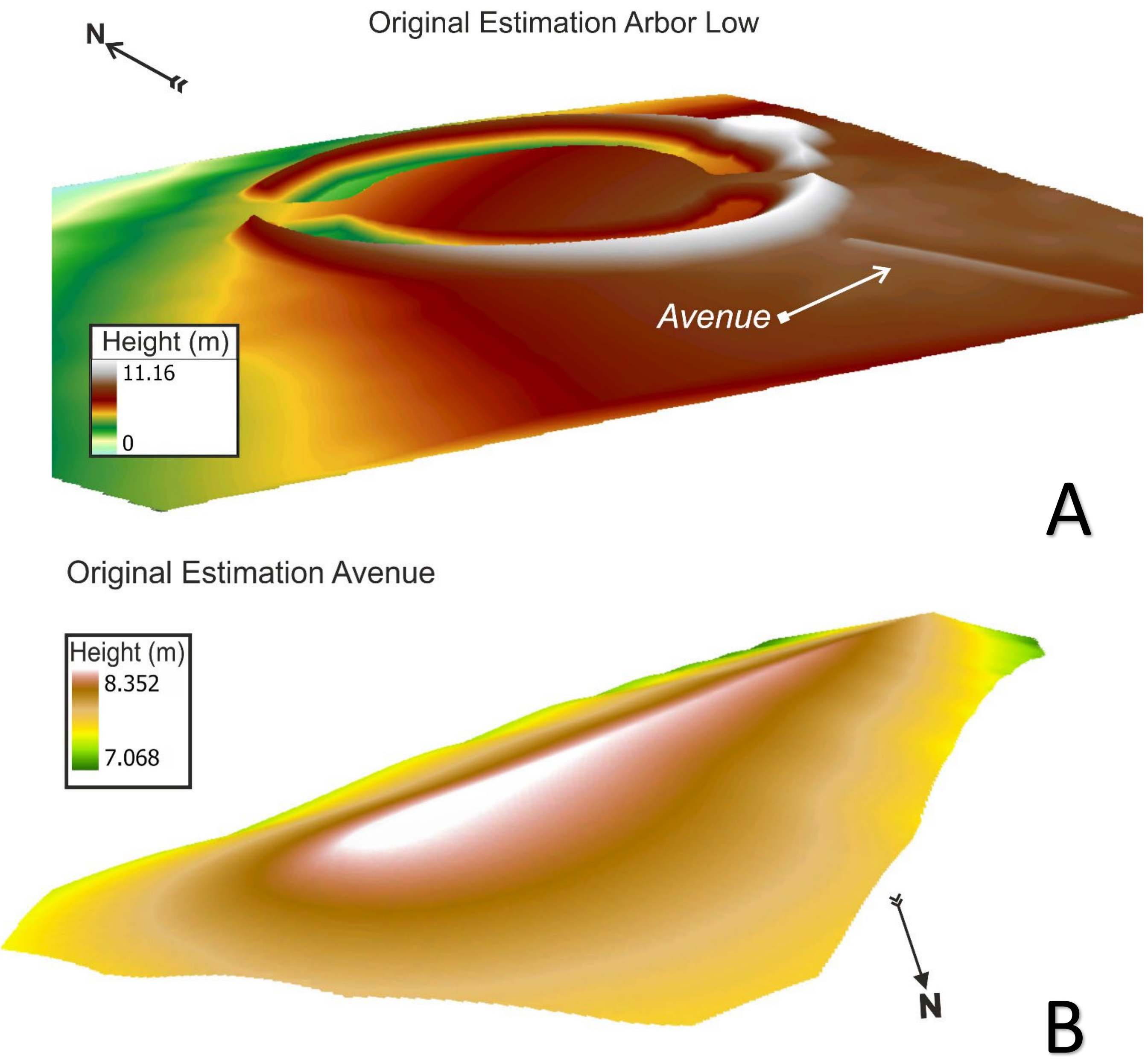


Figure 5.4: A) Using the OE results derived from the contemporary data gathered from aerial imagery and subsequent DEM, how Arbor Low may have appeared. B) The avenue close up, using the OE derived height.

Due to the minor height difference from OE to AE, the reconstructions look very similar (Figure 5.5).

The OE height, it must be reiterated, is based on a remnant height of the monument still present at the site today at 2.27 m. The AE height was sourced from archaeologists' estimations for the henge at 3 m for the embankments, and up to 4 m for the barrow (Figure 5.5a & b). An additional 10 % of the respective heights were used to create a single top point for the barrow rebuild.

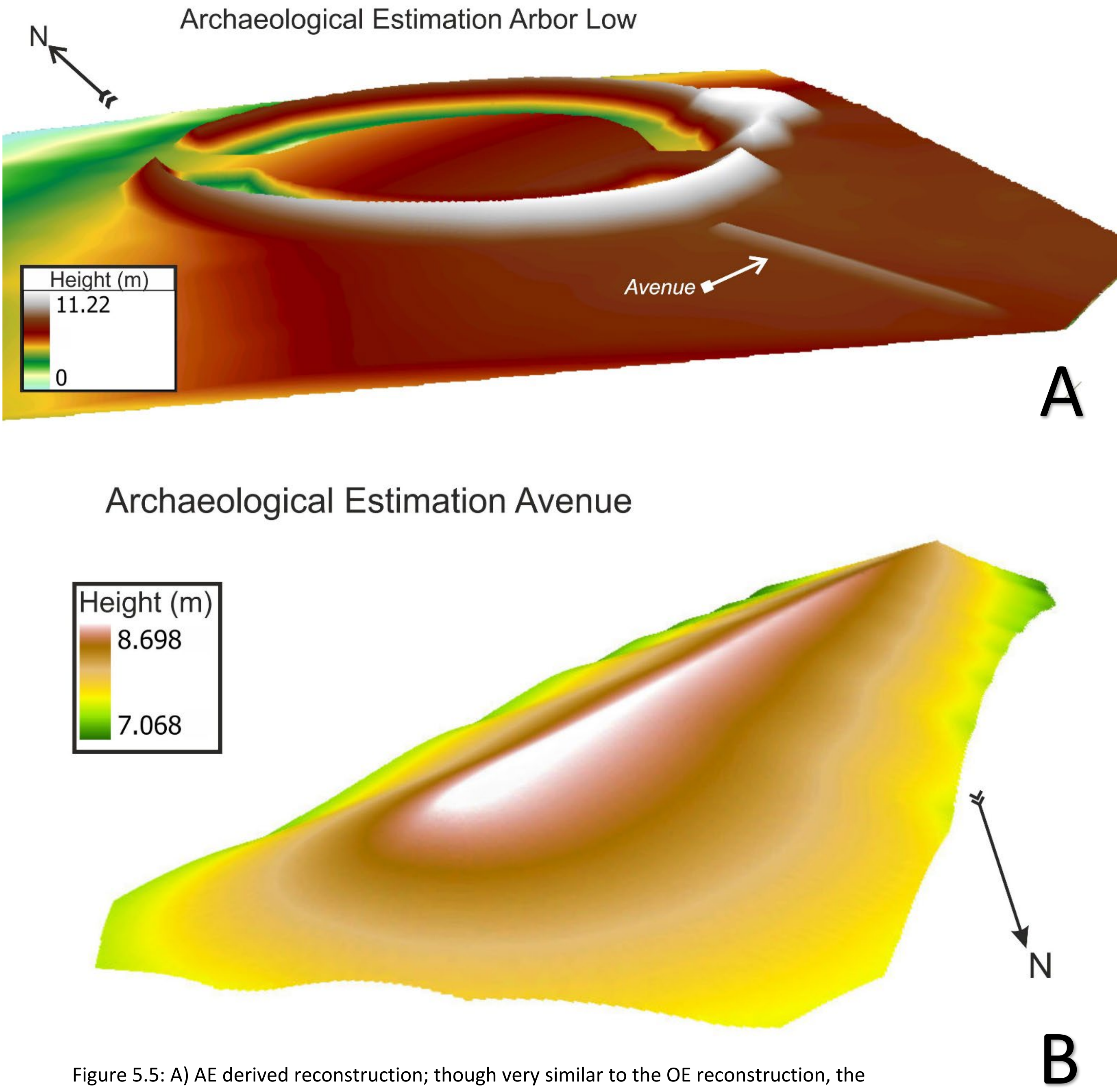


Figure 5.5: A) AE derived reconstruction; though very similar to the OE reconstruction, the embankments stand at a suggested 3 m from archaeologists. B) The avenue rebuild with a theorised height of 1 m, 0.4 m higher than the OE derived measurement.

Regardless of the level of similarity, the visualisations of the two theoretical rebuilds demonstrate a very distinct change compared to Arbor Low in the 21st century. Change – whether loss or gain – in material and structure is expected through the centuries. In both models, the change is apparent.

The level of detail is high; the resolution utilised in this investigation varied from 4 to 1 cm; Arbor Low's resolution here was 1 cm. However, by using such high resolution it can be a hindrance rather than helpful as it provides too much detail and when rebuilding the sites, results in edges and jagged creations that may not exist at lower resolutions (Nobajas *et al.,* 2017); Arbor Low has a resolution of less than 1 cm. Complete determination of this occurrence would require further testing, but that is not the remit of this investigation.

The main point of this investigation is to explore the effectiveness of combining UAV aerial imagery and GIS in monitoring and documenting damage to earthworth heritage monuments. Determining a rate of erosion up to this point in time would be difficult to calculate as so much of the history of Arbor Low implied it has been left out of any serious human impact (McGuire and Smith, 2008). The benefit of using a UAV is that the volume of the contemporary site can be completed any time a flight with a UAV is wished. This could form a new basis for consequential datasets and aid in determining a critical part of heritage health that was not necessarily easily completed beforehand. Such flights can be ongoing for whatever period of time is required to monitor a site, and therefore such analyses as well.

Following that, the data and measurements that remain at the site are important for the theoretical reconstructions. Therefore, using both primary derived data and archaeologists' estimations means that comparisons can be made between the two (Table 5.3); for Arbor Low, the McGuire and Smith (2008) suggested the embankments reached around 3 m high, the barrow up to 4 m, and the ditches varied between 2 and 3 m, so was averaged. The reasoning for utilising data derived from the investigation alongside prior research is to provide a connection to the archaeology and not just a physical geography point of view, thereby giving consideration to the London Charter (2009) that suggests clarifying that virtual reconstructions should be called theoretical, as they are imitations of a real feature or monument.

Though seeing the volumetric differences between the contemporary site and the theoretical rebuilds is observed in Table 5.2 and in Figures 5.4 and 5.5, understanding the volume lost between the contemporary site and the rebuild is needed in order to gain some insight into how much may have been lost since initial construction completion (Table 5.3).

Table 5.3: From the data in the prior table, the 2020 volume measurement is taken to be a percentage of the two theoretical Arbor Low reconstructions.

'AVENUE' CUT/FILL VOLUME (cubic metres)

MODEL	**EMBANKMENTS (incl. BARROW)**	**DITCHES**	**AVENUE**
ORIGINAL ELEVATION DEM	74.3	-68.4	60.8
ARCHAEOLOGISTS' ESTIMATION DEM	57	-56.4	39.7
DIFFERENCE	17.3	12	21.1

The volumetric difference is far more noticeable at Arbor Low with the AE rebuild. After following the parameters for rebuilding the embankments, barrow, and ditches using archaeologists' estimations, such a loss of extent could be defined as concerning. When these changes occurred cannot be definietively made; it could have been an ongoing process since the creation of the site, or something that has been more recent, such as modern farming techniques or tourism. On the other hand, the OE rebuild difference may be defined vulnerable and still require some level of monitoring in order to prevent further degradation.

5.3 Gib Hill

Gib Hill is one of a few combination long and round barrow monuments in the Peak District: it has a total length of 46 m and total width of 27 - 28 m, with the round barrow superimposed on the south-west end of the older long barrow (Historic England, 2022b). Two other sites have superimposition such as Perry Dale in the High Peak, 54 m long and 27 m wide, the long barrow is 0.5 to 0.75 m high north to south, and the round barrow a mere 1 m (Historic England, 2022c). Another is White Rake, near Great Longstone, the bowl barrow is roughly circular, at the east end and 1 m high, and the long barrow – oriented east to west – extends 24 m west of the bowl barrow, bringing the length to 42 m (Historic England, 2022d).

5.3.1 Visualising the Contemporary Monument: Gib Hill

The oblique aerial imagery from the UAV highlight paths walked by visitors to the site from the direction of Arbor Low, and over the barrow (Figure 5.6). The site was excavated in the 19th century by Thomas Bateman (Heathcote, 1940), who removed a cist piece from the site and had it displayed for some years at his Derbyshire home. It has since been re-appropriated back to Gib Hill (Heathcote, 1940) and now sits atop the round barrow in the flattened area as seen in Figure 5.6.

Figure 5.6: White arrows depict the desire lines up to the top of the round barrow and away to the stiles. The dashed white lines encircle areas of flattening or erosion, and the red circle is where the re-appropriated cist lies.

Damage at Gib Hill is not as apparent nor as concerning when compared to other sites in the investigation, but this is due to the protection of fencing (Figure 5.6) that has kept livestock away from the monument for the most part. However, cows had breached the fence prior to the investigation flight and may have caused some damage, according to the PDNPA.

5.3.2 Volumetric Results of Gib Hill: Contemporary and Reconstructed

Several rebuilds were created for Gib Hill: two for the round barrow and three for the long barrow. This was because researchers had proposed two different heights for the long barrow (Barnatt, 1989b; Historic England, 2022b). Like all the sites, a contemporary volume analysis was completed using the contemporary relative height DEM. The site has been fenced off to prevent livestock from damaging the feature, however cattle do occasionally push down the fencing and get in. According to the PDNPA and prior to data collection in February 2020, this had occurred and some damage was inflicted.

Before the volumetric analysis was executed on Gib Hill, several pits surround the barrows as described by Barnatt (1989b), who posited depths for these pits (see Table 5.4).

Table 5.4: Due to the dual barrows at Gib Hill, and the dual heights for the long barrow from Barnatt (1989b), Historic England (2022), and Bateman (in Heathcote, 1940) for the AE round barrow, meant several rebuilds were made.

GIB HILL – HEIGHT/DEPTH (metres)

RASTER CALCULATION	ROUND BARROW	LONG BARROW	PIT TYPE H	PIT TYPE I
ORIGINAL ELEVATION ROUND BARROW DEM	4.083	-	-0.544	-0.2
ARCHAEOLOGISTS' ESTIMATION ROUND BARROW DEM (BATEMAN)	5.5	-	-0.3	-0.5
OE LONG BARROW DEM	-	1.653	-	-0.2
AE LONG BARROW DEM 1 (BARNATT)	-	1	-	-0.2
AE LONG BARROW DEM 2 (HISTORIC ENGLAND)	-	2	-	-0.2

The type *'I'* pits likely reached 0.2 to 0.3 m (Barnatt, in McGuire and Smith, 2008), so 0.2 m was applied to all AE reconstructions of the long barrow and bowl barrow. The type *'H'* pits were either old, shallow quarries or related to construction of the bowl barrow, so Barnatt suggested they reached a depth of 0.3 – 0.5 m deep (Barnatt, in McGuire and Smith, *ibid.*). The final pits, type *'J'*, were the most recent and were likely post construction small-scale quarry pits as they reached between 0.2 and 1 m (Barnatt, in McGuire and Smith, *ibid.*). Consequently, these pits were ignored as their age would imply no connection to construction of either barrow.

Table 5.5**:** The varying volumetric results of the barrows at Gib Hill, which rely on varying estimations from researchers, past and present (Bateman, in Heathcote, 1940; Barnatt, 1989b; Historic England, 2022b).

GIB HILL – VOLUME (cubic metres)

MODEL	BARROWS (BOTH)	LONG BARROW	PITS (TYPES H, I, J)	PIT TYPE H	PIT TYPE I	PIT TYPE J
2020 DEM	1508.146	-*	-84.521	-58.677	-1.584 **	- ***
ORIGINAL ELEVATION DEM ROUND BARROW	1201.861	-	-385.116			- ****
ARCHAEOLOGISTS' ESTIMATION DEM ROUND BARROW	1504.970	-	-354.566	-	-	-
OE DEM LONG BARROW	-	953.909	-69.089	-	-	-
AE DEM LONG BARROW 1 (BARNATT)	-	574.221	-69.331	-	-	-
AE DEM LONG BARROW 2 (HE)	-	1153.014	-69.007	-	-	-
DIFFERENCE 2020 DEM/OE ROUND BARROW	306.285	-	-	-	-	-
DIFFERENCE 2020 DEM/AE ROUND BARROW	3.176	-	-	-	-	-

*Long barrow is part of the OE round barrow rebuild data.
** This is the only result for pit Type I not merged into other pit types, so used here.
*** Type J pits merge into Type H pits in the 2020 DEM, and so are counted with joint pit data.
**** Type J are considered to be post construction of either barrow so were not included in rebuilds, but are incorporated in the joint pit volume.

For the round barrow OE and AE rebuilds, three in total, each underwent volume calculation. It must be noted that, despite Bateman (in Heathcote, 1940) writing that the barrow was 18 ft. (5.5 m) tall at the time of publication, this could certainly be an exaggeration in the rebuild (see Table 5.4). The 2020 DEM volume for both barrows together was 1508.146 m³, which if compared to the AE rebuild for the round barrow would only be 3.176 m³ in difference.

However, that height likely was an exaggeration as has been mentioned. The OE rebuild resulted in a difference of 306.285 m^3, which may be more applicable (see Table 5.5).

In comparison to the AE rebuild, the OE rebuild appeared more reasonable, due to the use of remnant height data over evidence put forward in the 19th century, which may have been anecdotal, if not regarding another site. The OE height was calculated to be 4.083 m and the depth was 0.544 m, but only for pit type 'H', as Barnatt (1989b) posed a maximum depth for this pit type at -0.3 m. Those pit depths were used in both OE and AE rebuilds due to the merged nature today.

The long barrow was not given a new height in the round barrow rebuilds, instead left as it is seen today. This was because when it was at its own potential maximum height, the round barrow was not present, and the maximum height has two measurements posited by researchers. Hence three hypothetical rebuilds were created for the long barrow; firstly, Barnatt (1989b) suggested it was around 1 m high over a ditch – though he may mean the pits – and no higher. The second AE rebuild is derived from the height provided by Historic England; they posited a maximum height of 2 m (Historic England, 2022) and the possible reason for this difference between Barnatt and Historic England is possible from using a different point. This 1 m difference, however, would mean an adjustment in appearance for the long barrow.

The OE depth for the long barrow differed to the OE depth for the round barrow due to the fact that only one type of identified pit – type '**I**', as defined by Barnatt, in McGuire and Smith (2008) – were likely to be contemporary to the long barrow in age, and that the other types – '**H**' and '**J**' – were younger. Type '**H**' was considered to be contemporaneous with the construction of the round barrow, but may also have been post-construction quarry pits; for this investigation it has been taken as being of age with the round barrow. Type '**J**' pits were considered to be post-construction quarry pits, and not related to either construction. Therefore, the north east pits (Type J) and had to be 'removed' along with the bowl barrow in order to establish the remnant maximum height of the long barrow as it is today to determine an OE remnant height as accurately as possible. To do so meant creating a DEM of just the long barrow and the type ‘**I**’ pits. Consequently, this provided a different depth measurement for the long barrow rebuild.

5.3.3 *The Virtual Reconstructions of Gib Hill*

There were five reconstructions completed for Gib Hill: two for the round barrow and three for the long barrow. This was due to there being two theories provided by researchers (Barnatt, 1989b; Historic England, 2022b). Firstly, as described in Section *§5.3.2*, Table 5.4 and Table 5.5, there were numerous pits present, and all three types had a particular association with each barrow, only one type (Type J) was completely disregard due to being post-construction quarry pits, therefore younger than either barrow.

The OE rebuild of the round barrow included pit types H and I, as the former was associated with the round barrow and the latter associated with the older long barrow (Figure 5.7).

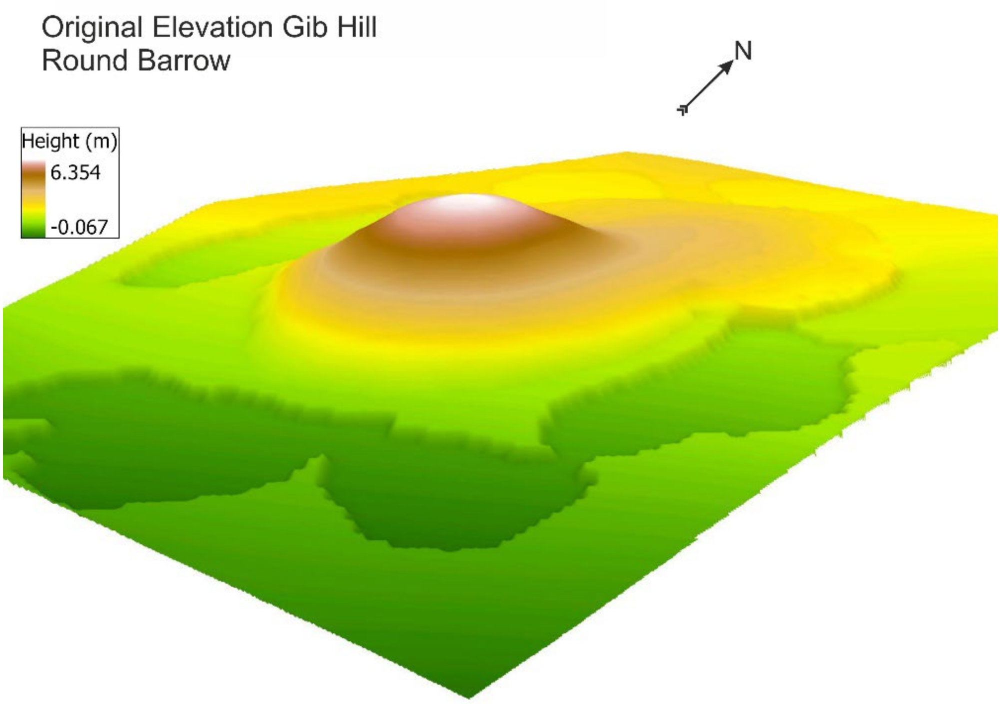


Figure 5.7: The OE derived reconstruction of the younger round barrow, the negative depth is due to the OE depth of 0.544 m, just over the maximum depth suggested by researchers.

The OE rebuild appears to be a good theoretical estimation into the former appearance of the round barrow at just over 4 m. The AE reconstruction however used a height that was provided in the 19th century, by Bateman (in Heathcote, 1940), when claimed it reached at least 18 ft. high (5.5 m). As can be seen in Figure 5.8, this may well have been an exaggeration if not a misunderstanding with another, similar feature elsewhere.

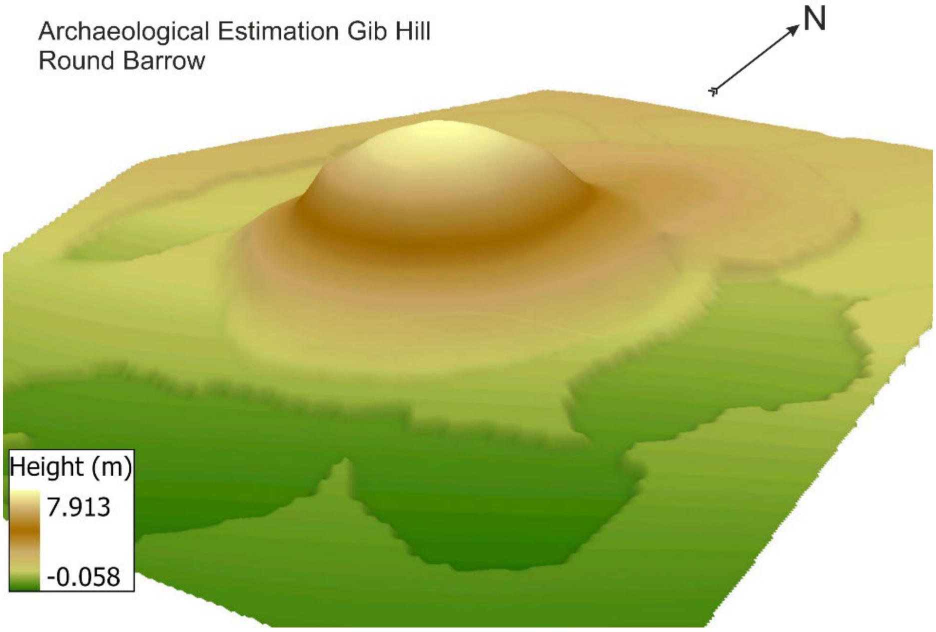


Figure 5.8: Using Bateman's 19th century estimation of 18 ft. / 5.5 m, the round barrow looks a little out of shape, though as a limitation, this could be as a result of computer based modelling.

Bateman's proposed height of 18 ft. has been considered an exaggeration by Barnatt (1989a), and in a survey completed by Barnatt (*ibid.*), the recorded height was 3.5 m at the time of the survey. This differs from the 4 m found in the investigation, but that height is determined in using a modelled topography that takes heights of the field around the monument to visualise a field pre-construction of either barrow. This could explain the half a metre difference between the survey of the later 1980s and this one.

Secondly is the long barrow. The nature of the barrows here is unusual but not unheard of as there are two other sites with superimposition of a round barrow atop a long barrow in the Peak District. Three theoretical models were created, one using OE data and two from archaeologists' estimation: Barnatt (1989b) and Historic England (2022b). The OE rebuild height sat between the two offered heights from archaeologists, and so partially acts as an average of the two AE heights (Figure 5.9).

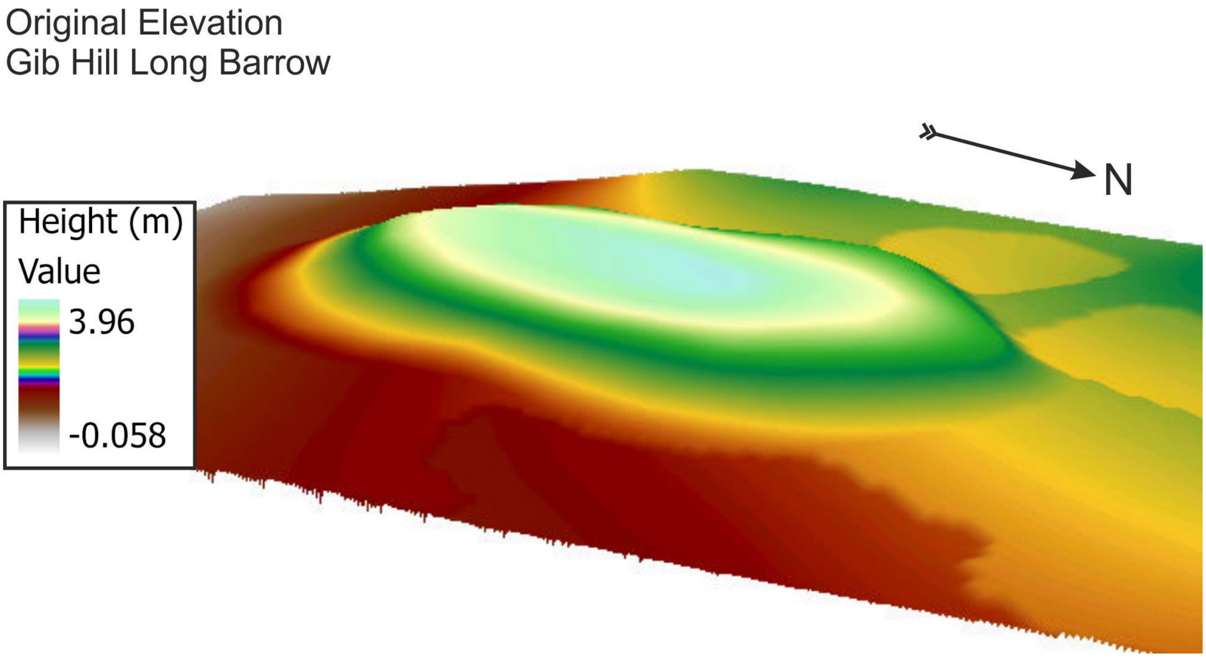


Figure 5.9: Using the OE derived height, the remnant from a raster calculation as if the round barrow did not exist.

Due to the reality that the long barrow has a comparatively younger round barrow superimposed atop it, the extrapolated remnant height is an estimation of exactly *where* did the long barrow begin and the round barrow start. However, due to its very central placement in between the two proffered AE heights, it may not be overly inaccurate.

The first of the two AE theoretical rebuilds utilises the smaller proffered height from Barnatt (1989b). Barnatt (*ibid.*) did note that it was 1 m high at the northern end and 1.5 m at the southern; therefore, due to the OE derived height being so close to the upper measurement, the 1 m was used (Figure 5.10).

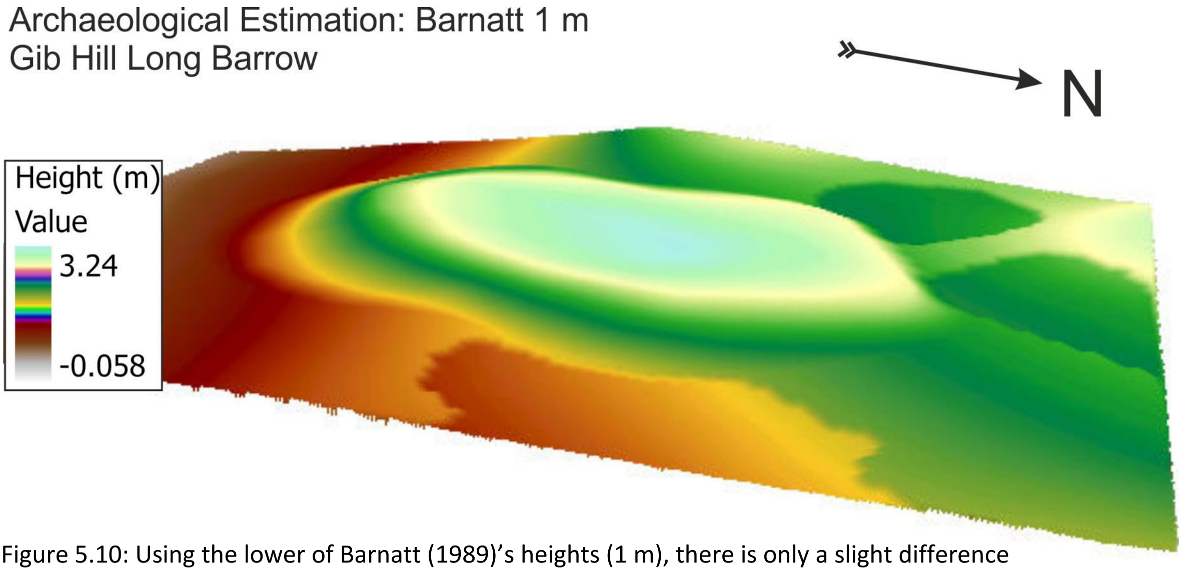


Figure 5.10: Using the lower of Barnatt (1989)'s heights (1 m), there is only a slight difference between this and the OE derived. By using the contemporary shape of the long barrow today in GIS means the shape can be highlighted for the theoretical model.

On the other hand, Historic England (2022b) proffered a height of 2 m. As acknowledged earlier in this chapter, the height difference may be because of HE and Barnatt using two separate initial measuring points. Consequently, the second AE theoretical model, whilst similar, and is close to the OE derived height, meaning any of the three are reasonably accurate digitally realised models (Figure 5.11).

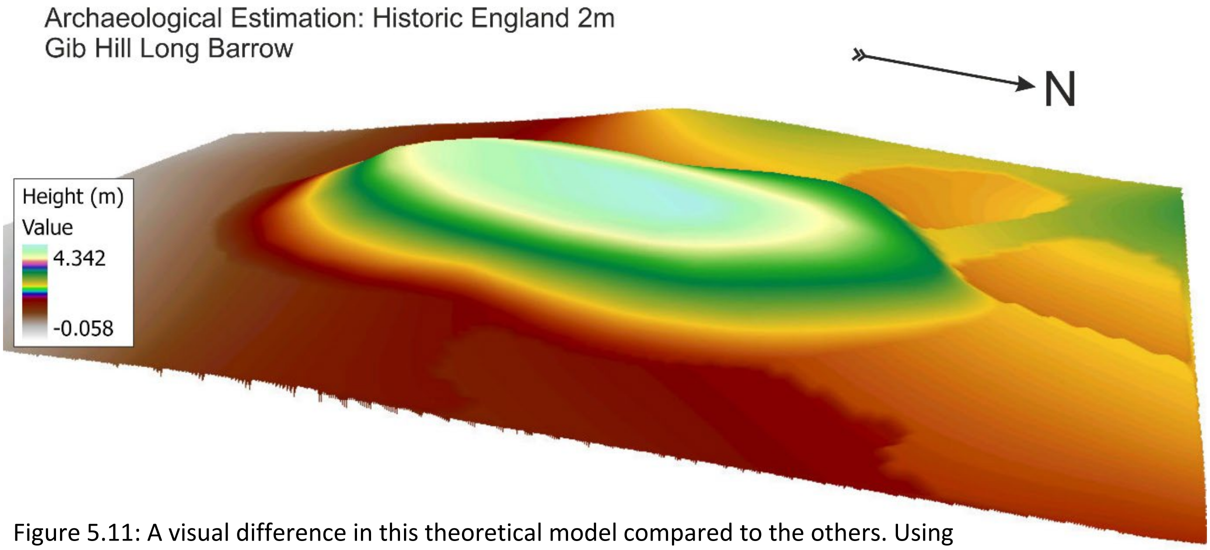


Figure 5.11: A visual difference in this theoretical model compared to the others. Using HE's posited 2 m height does lift the long barrow more. However, due to the tiny difference between all three of almost half a metre, they are all reasonable theoretical models.

Again, the high level of resolution may be impacting on quality inadvertently, by being overly detailed in the digitisation of the models (Nobajas *et al.,* 2017), such as can be seen on the edges of the third long barrow model (Figure 5.11).

Volume comparison, as completed for Arbor Low in *Section 5.2.3,* cannot be completed to the same extent here due to the superimposition of the round barrow, merging volume of both barrows into one measurement.

5.4 Bull Ring

The Bull Ring may have been built by the same large grouping of people who built Arbor Low (McGuire and Smith, 2008), but unlike that henge, the Bull Ring has lost all of its orthostats and has not been as protected – both indirectly and directly – so has suffered far more damage.

Like Arbor Low, Bull Ring had three sets of volumetric results and two hypothetical rebuilds, using the maximum height and depths left at the contemporary sites and estimations from researchers. Unlike any of the other sites, an equation was used to remove a tree that grew inside the henge, that would have impacted on the *raster calculation* had it been left. The equation can be seen in *Chapter 3.*

5.4.1 Visualising the Contemporary Monument: Bull Ring

The henge is scheduled, but because it is situated beyond the Peak District National Park limits, it is not protected by the PDNPA. This has meant the henge has suffered at the hands of farmers, quarrymen and local people over time (Figure 5.12).

Figure 5.12: Yellow lines show where visitors commonly walk across the barrow tops; dashed white areas show the severe damage present, particularly in the northeast corner from quarrying. The white line depicts where the main thoroughfare rests, outlined in red dashed lines.

Due to not having the same protections as Arbor Low (McGuire and Smith, 2008) the Bull Ring is damaged across the entirety. The current custodians– Dove Holes Community Association who own the nearby building – try to care for it as best as they are able, however it is a commonly used by dog walkers, families with children and young people who wish to make use of the recreation spaces around it. The *slope* and *hillshade* visualisations display this far better than the oblique angle used in Figure 5.12. The damage to the eastern side of the central plateau and the embankment is incredibly obvious in Figure 5.13a & 5.13b.

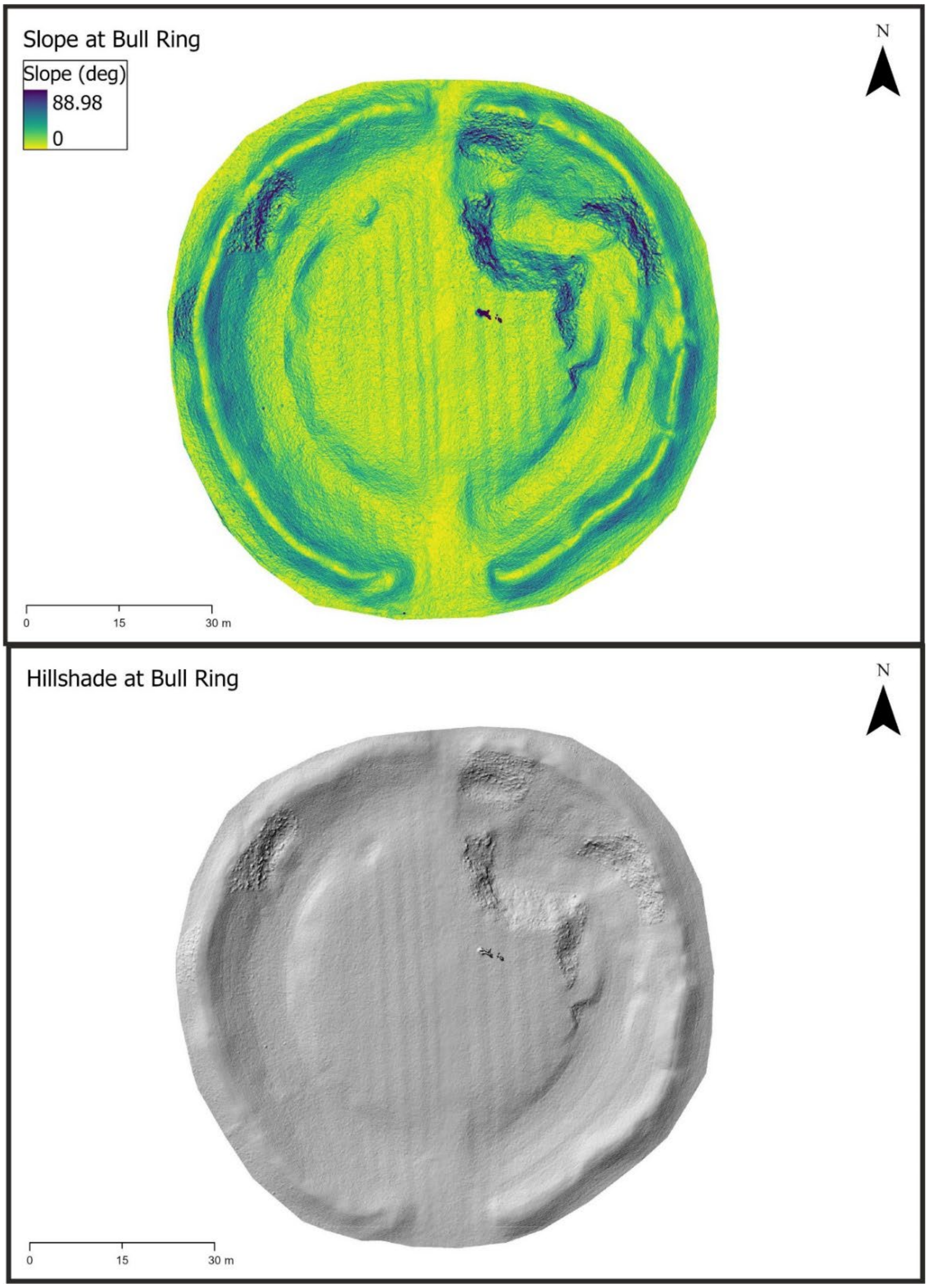


Figure 5.13: Slope (a) and hillshade (b) at the Bull Ring. The tree in the central plateau is very visible in the slope image, but the damage caused by quarrying attempts in the late 19th and early 20th centuries is prevalent in both images, and in both image, the ridge and furrow farming technique is clearly visibile with these visualisations.

5.4.2 Volumetric Results of Bull Ring: Contemporary and Reconstructed

Firstly, a volume determination was done of the contemporary henge at Bull Ring using the relative height DEM. This was impacted by the tree in the centre of the henge, so another DEM was made using *topo-to-raster* interpolation using the relative heights, just without the tree present (Table 5.6).

Table 5.6: From the raster calculated difference for Bull Ring. The central plateau is later split due to the nature of the calculation, but has no provided height as it is using heights from the modelled topography.

BULL RING – HEIGHT/DEPTH (metres)

RASTER CALCULATION	EMBANKMENTS	DITCHES	WESTERN PLATEAU	EASTERN PLATEAU
ORIGINAL ELEVATION DEM	1.475	-1.897	-	-
ARCHAEOLOGISTS' ESTIMATION DEM	3	-1.65 (avg.)	-	-
DIFFERENCE	1.475	-0.247	-	-

Barnatt and Myers (1988) suggested 2 m for the height of the embankments, however McGuire and Smith (2008) noted that Arbor Low and Bull Ring had similar dimensions, therefore 3 m was used for the Bull Ring as well. Barnatt and Myers (1988) suggested a depth between 1.2 m and 2.1 m for the ditches – again, it likely had an uneven base akin to Arbor Low – so an average of 1.65 m was used for ease (Table 5.6). The OE depth was within this estimated depth from Barnatt and Myers (1988) of 1.2 to 2.1 m.

In order to determine the OE heights for the Bull Ring, the *raster calculation* had another step to calculate the height difference. This was because of the presence of the tree in the central plateau that was around 3 to 5 m tall. An equation was used to remove those tree pixels and replace them with heights from around the tree, as explained in Chapter 4. This can be done individually for each pixel, or by using the histogram to determine when the tree heights end and start encroaching onto readings from the embankments. As the rebuild is hypothetical, so is the newly flattened area that was formerly the tree pixels by using a single pixel height from nearby on the plateau.

As with the other sites, AE heights and its associated rebuild were also volumetrically analysed using the *cut/fill* tool. Again, this can be compared to heights that remained at the site (OE heights) and with the contemporary henge (Table 5.7).

Table 5.7: The volume results merged parts of the plateau with the embankments, and parts of the berm as mentioned by Barnatt and Myers (1988) as existing.

BULL RING – VOLUME (cubic metres)

MODEL	BOTH EMBANKMENTS	MIDDLE OF PLATEAU	EASTERN EMBANKMENT	DITCHES + OUTER PLATEAU	WESTERN EMBANKMENT + WEST HALF PLATEAU
2020 DEM	1215.670	123.912	-	-1472.177	-
ORIGINAL ELEVATION DEM	1596.343	-	841.748	-1929.340	754.595
ARCHAEOLOGISTS' ESTIMATION DEM	2165.4	-	1141.728	-1678.121	1023.671
DIFFERENCE 2020/OE DEM	380.673	-	-	-	-
DIFFERENCE 2020/AE DEM	949.73	-	-	-	-

The results of the rebuilds are impacted by the fact that the Bull Ring has suffered damage over its lifetime. For example, it was almost completely destroyed by quarrying and the north-eastern side has defined areas of small scale quarrying present. The field in which it sat is now used for recreation used by dog walkers and local people, thereby creating pathways around and over it. Consequently, this will have impacted the results of the OE calculation and should be acknowledged.

5.4.3 The Virtual Reconstructions of Bull Ring

Due to the damage across the site over its lifetime, the remnant height and depth reflected this (Figure 5.14). The embankments are not as high as may be expected, particularly if the theory that it was constructed by the same population that build Arbor Low is true, and it is the most likely (McGuire and Smith, 2008).

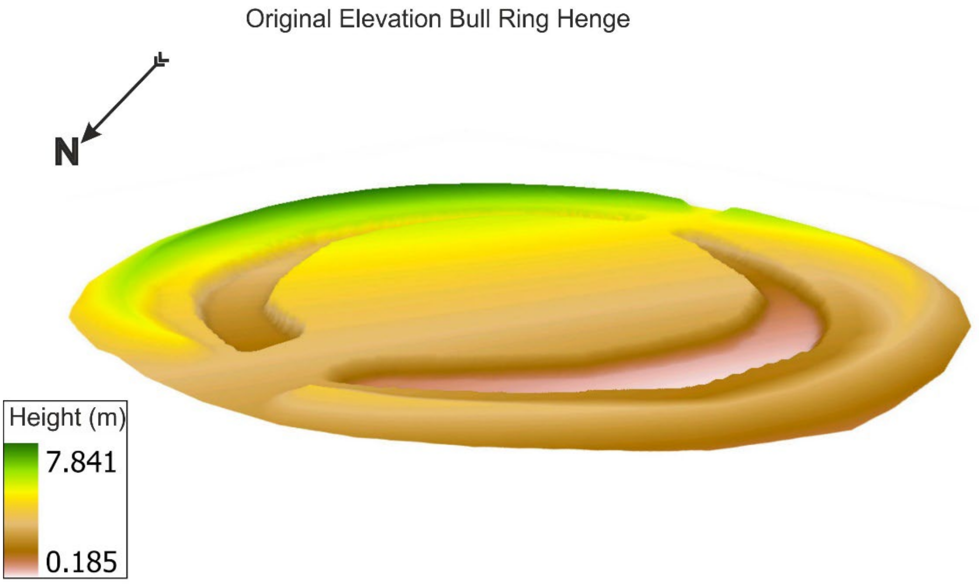


Figure 5.14: This theoretical model reached 7.8 m (from ditch to embankment top), but this may not have been the height it did reach. The embankments could have been 2 m (Barnatt and Myers, 1988) or 3 m like Arbor Low may have been (McGuire and Smith, 2008).

McGuire and Smith (p. 35, 2008) said that "*Bull Ring…although now damaged (and lacking orthostats) it is very similar to Arbor Low in dimensions and design…various factors suggest that these two sites reflect the original distribution of henges on the limestone plateau, and that they were built at the same date and functioned in similar ways*." Therefore, though Barnatt and Myers (1988) suggested 2 m for the embankments, the 3 m theorised for Arbor Low was used here if indeed they were once of similar dimensions and design (Figure 5.15).

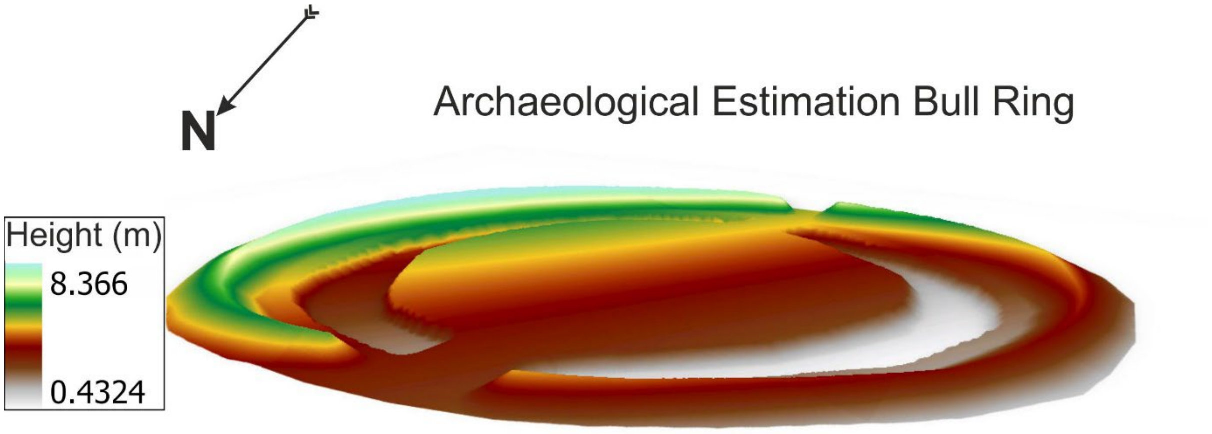


Figure 5.15: The AE theoretical rebuild using 3 m (McGuire and Smith, 2008) to better match with the similar Arbor Low henge.

When compared to the AE rebuild (Figure 5.15), the OE rebuild did look wanting (Figure 5.14). When the volumes are compared this is made plainer (Table 5.7), and if the contemporary volume is only a percentage of either theoretical rebuild, then the difference is highlighted further (Table 5.8).

Table 5.8: From the volume data (Table 5.7) the data in the prior table, the 2020 volume measurement is taken to be a percentage of the two theoretical reconstructions of Bull Ring.

BULL RING – Volume (%)

MODEL	BOTH EMBANKMENTS	DITCH + EASTERN PLATEAU	DITCH + WESTERN PLATEAU
OE DEM	76.15	68.4	60.8
AE DEM	56.14	56.4	39.7

If the AE rebuild is considered to be a good theoretical model of how Bull Ring may have appeared, that means the current Bull Ring is nearly half of what it may once have been in the past. In comparison, the OE rebuild – only utilising the remnant height and depth – displays a smaller loss of volume. Again, this remnant height is from what is currently the highest measurement still present on a site that has been damaged over its lifetime.

5.5 Pilsbury Castle

Pilsbury Castle was the largest and youngest site of the investigation. It was intended to push the boundaries of the methodology, and it did. Complete site-wide hypothetical reconstructions were not possible for this site without a wider and multidisciplinary focus, as the builders of the time used an already present headland along the River Dove (Landon *et al.,* 2006). However, an attempt was made on the eastern bailey hollow-way, and it was ‘filled in’ using last matching heights on the edge of the eastern bailey and on the motte. Overall, it was hard to determine where alterations had been made across the site and would benefit from a wider multidisciplinary investigation.

5.5.1 Visualising the Contemporary Monument: Pilsbury Castle

Despite the complexity at the site, Pilsbury was perhaps the best for utilising the visualisation imagery as part of documenting and surveying. Due to the size of the site and its relative isolation away from villages, it is more at the mercy of livestock, walkers, and wild animals, such as badgers. At the time of data collection, on the south-western most side, an embankment of a hollow-way beyond the southern bailey had heretofore unknown badger activity.

The aerial imagery alone aided in the identification of pathways that are then enhanced further with *slope*; including the pathway created up to and over the limestone knoll. Inside the last five years, the PDNP had alerted visitors to erosion damage on the eastern knoll; walkers have often climbed the limestone to its highest point, and this was evident in the creation of an unofficial path up to and over the outcrop seen in the aerial imagery (Figure 5.16).

Figure 5.16: A close-up (red box) of the pathway eroded into the knoll from repeated action by walkers up and over the slope, and up to the precipice (yellow). The demarcation of the main path for walkers is in the background (dashed line) (Source: H Malbon, 2020).

As with the other *slope* and *hillshade* tools were used; the *slope* (Figure 5.17) highlights the steep ramparts, and the trees on site.

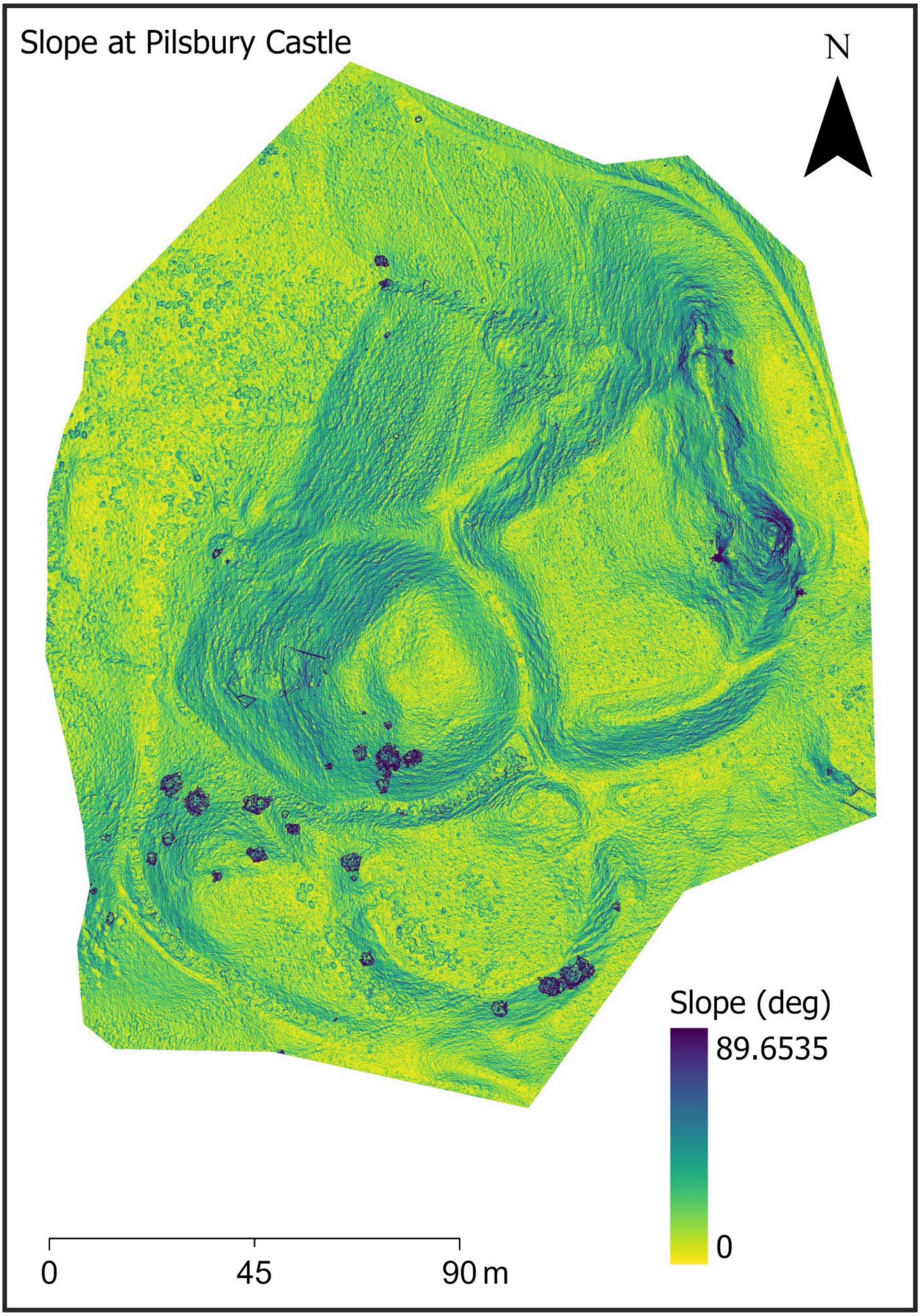


Figure 5.17: Slope of Pilsbury Castle, highlighting the ramparts, pathways and trees on site.

Whilst the aerial imagery – both oblique and not – are useful in identifying features across the site, the use of *slope* better identifies where even the faintest of pathways lie, due to the very high resolution of the images. So too, does hillshade (Figure 5.18).

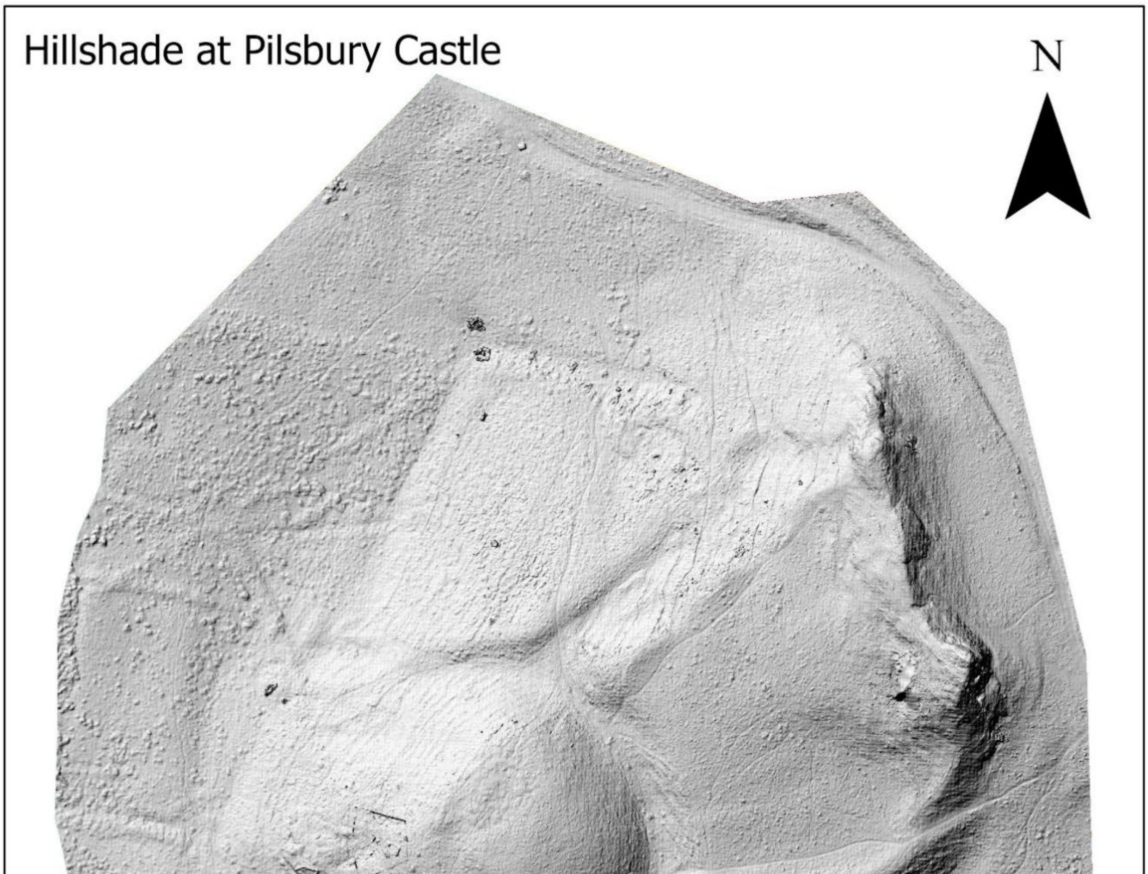


Figure 5.18: Hillshade also highlighting areas, including the trails left by people and animals, and damage by burrows, and the linear structures to the west are far more defined than in the slope visualisation.

5.5.2 Volumetric Results of Pilsbury Castle: Contemporary and Reconstructed

As mentioned, this site tested the boundaries of the methodology. It is the largest site, complex and compared to the other three sites, it was built from a naturally formed headland (Landon *et al.,* 2006). A small alteration was attempted, however, on the eastern bailey hollow-way as these were either already present, therefore were deepened during construction of the earthworks, or they were created during construction (Landon *et al.,* 2006).

From the relative height DEM, the highest matching height on the eastern bailey close to the motte was used as the OE measurement in that area in order to rebuild the hollow-way, if indeed it was not an already present ditch of some kind, but was newly created at the time of castle construction (Table 5.9).

Table 5.9: Unlike the other sites, Pilsbury Castle pushed the limits of the methodology, and any reconstruction had to be improvised and focused on a smaller area.

PILSBURY CASTLE – HEIGHT (metres)

2020 RELATIVE HEIGHT DEM	**RELATIVE HEIGHT DEM HIGHEST POINT**	**HIGHEST MUTUAL HEIGHT (ON EITHER SIDE OF HOLLOW-WAY**
MOTTE	28	27
EASTERN BAILEY	36 (excl. limestone knoll)	27

The material removed from the hollow-ways was suggested to have been used to raise the height of the motte by almost 30 m (Landon et al., 2006). The result of the theorised alteration – a refilling of the ditch if it was newly created – can be seen in Table 5.10.

Table 5.10: Unlike the other sites, Pilsbury Castle pushed the limits of the methodology, therefore so did the volumetric analysis, which 'lost' material if indeed the hollow-way was completely dig out during construction.

PILSBURY CASTLE – VOLUME (cubic metres)

MODEL	*HOLLOW-WAY*
EAST BAILEY + HOLLOW-WAY OE DEM	-1312.33

Obviously, this is just a part of the castle, and an OE measurement cannot be achieved well enough due to the nature of the landscape present, as it is a natural headland (Landon *et al.,* 2006), therefore the highest similar heights were chosen to 're-fill' the hollow-way. Since this data was determined using the contemporary site and the re-filled hollow-way, there are not any other analyses of volume to be determined.

5.5.3 The Virtual Reconstructions of Pilsbury

Due to the size and therefore complexity of the site, a wide-scale rebuild was impossible, not without a multi-disciplinary investigation to fully implement the methodology. This site was chosen to specifically test the limits of the methodology using interpolation and volumetric analysis tools. To improve this outcome for Pilsbury, a multi-disciplinary approach would be best. However, a small, focused rebuild was completed on the hollow-way separating the motte from the eastern bailey (Figure 5.19a & b).

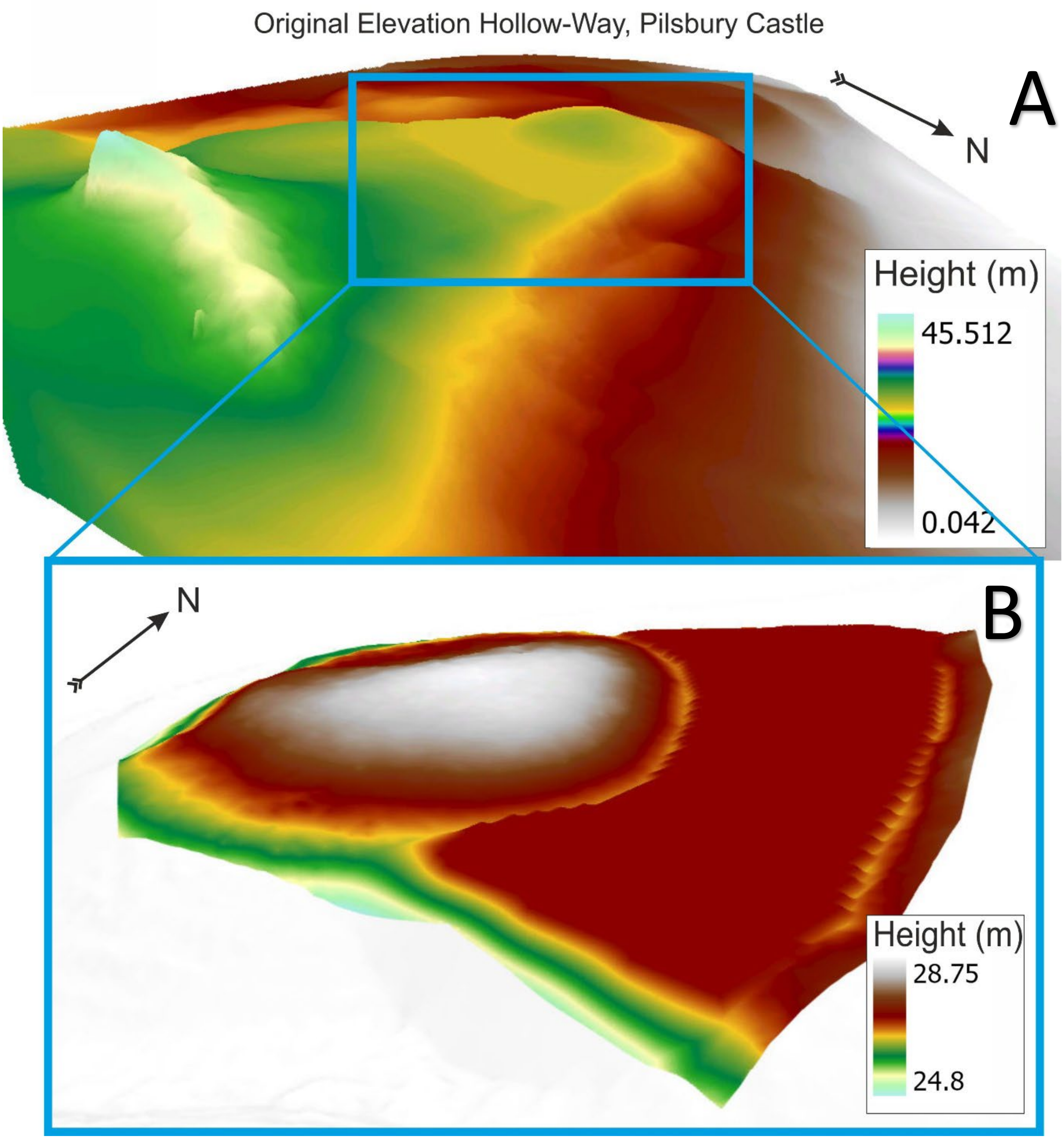


Figure 5.19: A) A wider view of Pilsbury OE rebuild, depicting where and which hollow-way is being described. B) A focused presentation of the rebuilt hollow-way; note the dips on either side that demarcate the limits of the data points, a flaw to factor in if a rebuild is completed again.

As noted, Figure 5.19b has dips either side of the rebuilt hollow-way section. This is because of the demarcated zone designated for the data points. This is a flaw of the implementation of the zoning, but it was not going to be an easy rebuild to complete overall. If ever done again, this could be remedied.

Damage is present at the site, so volumetric analysis would benefit, particularly if done on focused areas to ensure best coverage. A site wide survey could also be done to understand site wide health as well, and can also be done as often as would be required.

5.6 Standard Error

As previously mentioned, these DEMs created inside the Agisoft workflow were converted frfom absolute height to relative height, in order to better present the height data in the calculations, and also to address any possible side effects of GPS and/or UAV height data problems. In this investigation, the handheld GPS was not always accurate with regard to elevation of the site at the GCPs. Convversion to relative height also meant the data could be better presented clearly and prevent any potential confusion with the calculations.

The error was calculated by taking the GPS elevation reading in metres away from the DEM elevation reading by following this formula:

$$GPS/MODEL * 100 - 100)$$

This was applied to each site, using the orthomosaic and Agisoft DEM overlaid at a transparency of 50% in order to select the spot height at the GCPs set out at each monument. The results were then averaged to provide the standard error (Table 5.11).

Table 5.11: The calculated error for each site from the GPS (handheld) readings at each GCP.

Arbor Low	***GPS (m)***	***MODEL DEM (m)***	***ERROR (%)***
GCP			
A	414.88	415.6080020	*-0.17517*
B	417.98	418.001221	*-0.00508*
C	417.25	417.420417	0.0023
D	414.046	414.045959	0
E	419.173	417.099945	0.49702
		AVERAGE =	***0.06381***
Bull Ring			
A	387.695	387.315795	0.09792
B	385.262	386.514343	-0.32401
C	383.28	385.445862	-0.56191
D	385.581	383.47879	0.54819
		AVERAGE =	***-0.05995***
Gib Hill			
A	419.96	417.817291	0.51283
B	418.419	419.620544	-0.28634
C	417.836	419.895233	-0.49042
D	419.601	418.447174	0.27574
E	423.009	422.966827	0.00997
		AVERAGE =	***0.00436***
Pilsbury Castle			
A	315.477	314.781494	0.2209
B	305.475	305.082977	0.1285
C	301.823	302.819702	-0.32914
D	306.116	306.034546	0.02662
E	305.073	303.723389	0.44436
F	306.699	307.027191	-0.10689
G	313.489	314.553375	-0.33838
		AVERAGE =	***0.00657***

Chapter 6 Documentation and Visualisation

This chapter discusses the advantages and disadvantages of the UAV-derived 3D models. It shall discuss the benefits of UAV monitoring of earthwork heritage sites, and what the models created can be used for beyond research alone. It shall also cover the limitations experienced in this investigation as a result of this method, and how they could be remedied.

6.1 Advantages and Disadvantages of Utilising UAVs for Heritage Site Monitoring

6.1.1 Disadvantages

As has been discussed in prior chapters, there are some disadvantages to using UAVs as part of monitoring heritage sites, with there being two main problems encountered:

- Flight restrictions
- Environment

Regarding flight restrictions, the issue pertained around the changing of batteries. This happened at all four sites. Whilst the near half an hour battery life was the limit and the DJI Phantom 4 in this investigation flew up to that limit, had any other sensors been added to the body of the UAV, the increased payload would have decreased the flight time.

Consequently, this would have meant the need for more batteries. As was noted in Chapter 4, batteries can be expensive and hard to transport overseas, though this latter concern was not faced here. For larger heritage sites in the UK, however, the operator would need to be sure all batteries are fully charged ahead of time and that enough batteries are available; the latter could be challenging due to battery costs, currently £169 each according to DJI (2023).

Regarding environment, it was largely the concern at Bull Ring and Pilsbury Castle. As discussed in Chapter 4, heavily vegetated environments impact the accuracy and usability of aerial imagery gathered solely from an on-board camera lowers (Bollandsås *et al.,* 2012). The landscape of the the Peak District is largely moorland, with areas of woodland interspersed (*see Chapter 3*).

At Pilsbury Castle and Bull Ring, trees were the environmental concern. At Bull Ring, a tree grows in the central plateau. Upon importation into GIS, it was recognised this tree would impact the height measurments. As a result, a way had to be devised to remove the tree. This was completed, however, it was an extra, unexpected step in the workflow that was necessary to achieve appropriate measurements.

Pilsbury Castle sat on on a headland on a riverbank, and this is where trees are commonly found in the Peak District. Consequently, prior to importation into GIS, the trees had to be edited out of the 3D model in Agisoft Metshape, however, it couldn’t completely remove all trees as any imagery of the castle could also be accidentally cut away. There was also a tall tree on the western side of the limestone knoll that arched over the eastern bailey. It could not be completely removed, but it did not impede much on the measurements. Finally, due to the complex nature of Pilsbury Castle, the remaining trees visible in the DEM did not impede with the focused hollow-way volume analysis. However, they would have to be removed if a site wide volume analysis was desired, as they would impact measurements. In that instance, they could be removed in a similar fashion to how the monuments were removed in the other three sites prior to generating a modelled topography.

Whilst they can reach inaccessible areas, the environment and vegetation height has a large impact; this is where LiDAR performs far better (Bollandås *et al., ibid.*). When the need for more sensors is required, it can be another expense, which, as Zhou *et al.,* (2020) acknowledged, is still a challenge faced by ALS despite being popular with archaeologists. Sensors also drain the battery life, for example DJI Phantom 4 has an almost half an hour of flight time, very useful for this particular focused landscape surveying, but added sensors would add more to the payload, lowering flight time and would mean more batteries – these can also be expensive and are difficult to transport overseas – would be required and more stops to change batteries during fieldwork as payload can impact flight time (Mohsan *et al.,* 2022). However, Shadiev and Yi (2022) have said that the flight times in UAVs is generally disadvantageous, alongside restrictions for flying, which impacted UAVs being used in an educational situation.

6.1.2 *Advantages*

Ultimately, the intent of the visualisations and volumetric analyses in this investigation was to explore the effective use of UAV-derived aerial imagery in the documentation and possible monitoring needs of earthwork heritage sites. Firstly, in brief, the benefits of UAV aerial imagery are as follows, particularly the model used in this investigation:

- DJI Phantom 4 is portable due to its size,
- Good flying time for this type of research, with few battery changes required;
- Automatic return to take-off area and continued from where it left off after a battery change,
- Ability to pre-plot flightpaths that can be repeated,
- Can select overlap percentage for coverage of the area
- Automated image collection determined by the flight path and overlap; and
- Very high-resolution imagery, down to 1 cm, with geotagging

6.1.3 UAV Flight Effectiveness

As documented by Themistocleous *et al.,* (2015) at Asinou Church in Cyprus, and Vilbig *et al.,* (2020) at the Cahokia Mounds in the USA, this investigation agrees that the DJI Phantom 4 is highly beneficial to use in research and monitoring for earthwork heritage sites. It is a versatile UAV and it was aided by the fact that these sites in the Peak District are in low vegetated areas, which Bollandsås *et al.,* (2012) and Risbol and Gustavsen (2018) found to rival LiDAR derived imagery in the same environment. Due to the expense of equipment such as imagery gathered by helicopter, the UAV is comparatively more cost-effective for NGOs to purchase for their own use as they are commercially available for private people, or to purchase via a third party, to gather imagery. Sozzi *et al.,* (2021) determined, despite costing around €43 per hectare via a third party, UAVs provided high resolution imagery with no minimum required area unlike satellite imagery. Even if an external company was required to gather data for NGOs, the imagery for the chosen site or area would be very detailed; this is supported by White *et al.,* (2022) who argued that in gathering data on intertidal sediment disturbance, UAVs gathered a significantly higher percentage of sediment compared to the walk-over method done on foot. White *et al.,* (2022) said UAVs had the highest upfront costs at £14,045 for equipment and training, compared to the walk-over method and aerial imagery taken from the Channel Coastal Observatory. This could be argued to be expected as the walk-over method did not require the same level of training, however they do acknowledge the UAVs are one time costs in purchasing the UAV, software and accessories (White *et al.,* 2022).

A minor issue that can occur is height determination. In the DEM the height data in this investigation had the height (altitude) of the UAV, not of the ground. As a result, the DEMs were converted into relative height from absolute height. The height difference would remain the same, therefore the results would not be impacted. The additional benefit was that the measurements were easier to understand and display. This can be mitigated by more GCPs than four, as Hill (2019) explained, which are useful for accuracy. Notwithstanding, others have concluded that UAVs are generally very accurate (Vilbig *et al.,* 2020), yet this can be resolved and will be discussed in the following section.

This investigation's resulting imagery had high resolution approximately between 1 and 4 cm, well enough that the ridge and furrow farming style commonly found in the Peak District, as mentioned in Chapter 3, can be seen at Bull Ring – this being evidence of the far different timeline at Bull Ring compared to Arbor Low, despite being considered comparable (McGuire and Smith, 2008). The level of detail showed where sheep trails and manmade pathways crossed the fields and over Pilsbury Castle, Arbor Low and Gib Hill. In the case of the latter, the imagery highlighted erosional damage to the barrow sides. This level of detail has been observed in other investigations for other cultural heritage features, for example Taddia *et al.,* (2020)'s investigation into assessing the quality of photogrammetric models for façade and building reconstruction, where an offset of 5 cm was present even without GCPs. Taddia *et al.,* (*ibid.*) also used a DJI Phantom 4, and stated it was a versatile, lightweight UAV, easy-to-use UAV making it a widely used solution for use in aerial photogrammetry. This was found, again, in this investigation.

This investigation, alongside Sozzi *et al.,* (*ibid.*)'s work, agree that the level of detail and the high resolution was very well suited to the purpose of this investigation: to highlight they are not only effective, but are cost-effective platforms in the long term because of the documentation ability and the potential to monitor changes at earthworks as often as needed.

6.1.4 Geotagging, Flight Planning and Battery Life

A highly important aspect for accurate 3D surfaces, such as DEMs, is the ability to geotag images (Kalacska *et al.,* 2020); the DJI Phantom 4 had on-board geotagging (coordinates attached to each image), which made the alignment process easier, which shall be discussed in the next section. This made the aligning effective and straightforward later in AgiSoft software, and the

SfM algorithm created four, highly detailed DEMs that were viable for use inside a GIS, which highlighted the effectiveness of the methodology by combining UAV-derived aerial imagery, SfM software and importation into a GIS. Geotagging also provided elevation, but it is that of the UAV, not the site, as was briefly discussed in the prior section. However, the DEM was converted into relative height, therefore the height difference across an investigation site was well defined, and easier to understand visually.

Continuing, the 27-28-minute battery life of DJI Phantom 4, and the relatively simple changeover of batteries when required, made this UAV advantageous in monitoring of these heritage sites in the investigation, because they were of a good size but did not require more than one battery change on-site during the flight. Hardin *et al.,* (2019) stated that battery life can be changeable, but this is based on altitude, flight speed and additional equipment added to the payload of the UAV; this issue was negated because the only piece of equipment required for this investigation was the on-board RGB camera on the DJI Phantom 4; there is no additional payload that would take away from the near half hour battery life. When batteries needed to be changed, the DJI platform had an automatic return to take-off/landing point feature, and once the swap over had been completed, would return to the point it left on its flightpath. This DJI platform works with most major flight planning software and applications, and the app selected for this investigation was *Map Pilot* by Drones-Made-Easy (2019).

This app was user-friendly, had overlap control which is essential for ensuring complete coverage of each site was achieved, automatic camera triggering up one image every 2.5 seconds, and when a flightpath had been decided and uploaded, the app determined the image collection based on the created flightpath. It also provided an expected flight-time, so that the UAV controller could prepare for any battery changes. *Map Pilot* was designed for DJI UAV platforms, and it even has a live feed of the UAV as it follows the flightpath on the tablet or smartphone that is used, in this investigation an iPad was utilised. Overall, this particular app was best suited for flight planning and imagery collection.

Following on, during any battery changes, the UAV returned directly to its launch point, and can be manually or automatically controlled for landing. Once the swap over has been completed, the next advantage of this UAV and app is that the platform returned to the exact same point it left before the battery change. This meant that the data collection would continue on smoothly, and there was no need to manually control or estimate roughly where to return the UAV mid-flight. Other investigations have used this app with DJI platforms, such as Saad and Tahar (2019) with successful results of detailed and accurate measurements of road ruts and potholes, not overly dissimilar to detecting areas of concern on heritage earthwork sites; and also for tree segmentation (Carr and Slyder, 2018).

6.2 Advantages and Disadvantages of AgiSoft Metashape and GIS Software

6.2.1 Disadvantages

As with anything done on computers and digitally overall, whilst the intent may be to present this type of data as credibly as possible, it will always be digital, and this can mean particular ways of displaying data may appear very sharply or angled. When used in conjunction with very high-resolution imagery, in the Arbor Low reconstruction, parts of the barrow on the southern side of the henge, displayed as very straight, defined edges, particularly towards the top of the barrow. Of course, this is not how it would have ever looked, now or in the past. The pits at Gib Hill are also very straight edged in a way that is clearly computerised, and is a fact of any computer model like this.

The method of creating a shapefile line and generating points along it every 1 m on such high-resolution imagery and DEMs, where there is a lot of height data stored within, may not be wholly effective. Instead, there may be the need to either have a lower resolution of data than what is gathered; this could be lowered within image or visualisation generation in order to smooth the edges. Another way instead would be to generate more points along the line by lowering the distance from 1 m to half a metre, in order to extract more of the available height data.

There would need to be more testing to determine if this is the cause of the very straight lines seen in the reconstructed DEM of Arbor Low. As Nobajas *et al.,* (2017) determined, sometimes having too high a resolution can interfere with the intent; in their research, the high-resolution data highlighted far more than expected, to the extent that the smallest of alterations in water channels was detected and impeded the investigation's aim, all by being too detailed.

However, this may not have been caused by the high resolution of the data and imagery, but is simply a fact of how computers and the software function, and drawing 'smooth' lines is not always achievable due to that facet of the methodology, or intrinsic to computers as a whole. It is a computer based model, so natural features will not always appear natural.

Pilsbury Castle was chosen to test the limits of the computer element of the methodology. It was built on a natural headland (Landon *et al.,* 2006) and so determining what was, and was not, originally present was harder to determine. As a result, the attempts would lead to unpredictable shapes, or it would show there had a been a low level or lack of change to an area at the time of construction or over time since ruination of the manmade buildings; as Barnatt and Smith (2004), due to lack of intensive farming in the gritstone moors – the Dark Peak, mostly – the area in which Pilsbury Castle is a buffer zone between the White and Dark Peaks, which has resulted in aspects of antiquity still being is use today. Landon *et al.,* (2006) determined that the contours of the site were largely natural despite alterations on the motte in the centre, but where exactly the build-up began was estimated to be around the lowest height of the eastern bailey, hence the attempted reconstruction of filling in the hollow-way between the two features. However, this leads to more questions, which will be discussed in *Section §6.5*.

Regarding Agisoft, it is a high performance software and requires a high performance computer which is capable of running the programme and graphics processing (quan Li *et al.,* 2016). As explained in Chapter 4, it also requires a large amount of RAM and storage for the amount of data, particularly if highly detailed 3D models are needed, as it can be of considerable size (de Reu *et al.,* 2014). In order to mitigate that concern, a 1 Terabyte external hard-drive was used to store all images, GIS outputs and projects. It is advisable to have a powerful computer configuration with advanced graphics card, 12 gigabytes of RAM and a 64-ibt operating system to utilise the software effectively and without issue (de Reu *et al.,* 2013).

As Unger *et al.,* (2020) described, there are elements lost in these sites because they are incomplete. For example, the Bull Ring and Arbor Low were once comparable, yet the former has suffered far more – quarrying threats and farm damage which can be viewed in the DEMs, hillshades and slope imagery in Chapter 5 from ridge and furrow style farming (Edmonds and Seaborne, 2001).

6.2.2 Advantages

After data collection, the images were uploaded to an external hard drive to begin alignment and point cloud creation in AgiSoft MetaShape. This software has long been used by professionals for heritage 3D modelling, and this investigation agrees it is a good software for such research. GIS software has been used in archaeology since the late 20th century, but there is no GIS software dedicated to archaeology alone, as was discussed in Chapter 2; it is used, comparatively, more in geography, geology and other disciplines. However, as in Chapter 2, the usage then was more for settlement modelling, but mapping is now being used more exstenively with GIS for heritage monitoring, becoming a standard that Lai and Sordini (2013) suggested it should, particularly for the managing, connecting and analyses of differnet data types (Fang *et al.,* 2022). It has also been used for spatial patterns of sites and communication paths in Bronze Age Crete (Siart *et al.,* 2008) and reconstruction of Neolithic landscapes in Thessaly, Central Greece (Alexakis *et al.,* 2011), to name a few examples, and Historic England utilise UAVs and GIS for analysis of wall and roof conditions, recording excavated features, site condition analyses, and SfM based 3D modelling (Historic England, 2023).

The advantages of these two programmes are as follows.

Firstly, AgiSoft:

- Relatively user-friendly interface,
- Provides a workflow to follow from the start,
- Can add in Ground Control Point data if needed/present,
- Can choose level of detail from low to very high,
- Can switch between completed layers to view with the next layer atop; and,

- Alignment is automatic and completed using the SfM algorithm.

Lastly, GIS software, Esri ArcGIS Pro:

- User friendly interface,
- Can import data from AgiSoft for use, e.g. the DEM and orthomosaic,
- Create DEMs,
- Can transform, add, take away from the data imported, e.g. using *clip* tool,
- Quick editing whenever needed with no extra steps,
- If geotagged, establishes the correct co-ordinate system for the aerial imagery and DEM,
- Can view in 2D and 3D within the same software,
- Variety of tools for visualising, highlighting and analysing with regard to landscape; and,
- Repeatability and ability to use data for comparison over time

6.2.3 AgiSoft MetaShape

Though there is other modelling software available such as Pix4D, AgiSoft MetaShape has been acknowledged to have increased alignment rates, fine orthomosaic resolution and SfM ground samples that are improved (Fraser and Congalton, 2018; Tinkham and Swayze, 2021), and Lastilla *et al.,* (2021) termed it as being one of the latest accurate and reliable pieces of software, even when in use with satellite derived imagery from multiple satellites, the workflow process works similarly.

Since the software is available commercially, it is used by many research groups globally and does not require very high levels of ability in the use of stereo-photogrammetry (Laporte-Fauret *et al.,* 2019). DTMs are needed in archaeological mapping and analysis, so the largely user-friendly nature of Agisoft compared to other algorithms and software (Howland *et al.,* 2022). In this investigation, the workflow accessible on the top bar of the interface was easy to follow and to edit detail levels, e.g. high, very high, within the dialogue boxes.

Once the workflow was completed, the different layers could be switched on and off in order to see the layer below by using the designated buttons on the toolbar above the workspace in the interface, and far more other tools are available in this software, some of which are automated and others that are manual, which Howland *et al.,* (*ibid.*) considered to be a negative that some aspects needed a manual control in order to fix or tweak a result. Like Howland *et al.,* (*ibid.*) went on to state, Agisoft is a boon for researchers of all landscapes but the most densely vegetated, making it a cost-effective tool over others. The results from this investigation also supports this as, overall, Agisoft Metashape was a very functional piece of software to use in this type of research, as it can facilitate GIS-based analyses, both straightforward and sophisticated types (Howland *et al., ibid.*).

6.2.4 Esri ArcGIS Pro

Esri's ArcGIS is a commercially available GIS software, commonly used within academic settings, and ArcGIS Pro, the newest version of the platform, was utilised for this investigation due to the accessibility and the new interface layout, which was far more user-friendly and intuitive than earlier versions; it was a ribbon interface, akin to programmes like *Microsoft Word* and others.

A main advantage is the fact that editing is always on in this newer version of ArcMap, which had to be turned on and off in older versions; this iteration could be edited without that need (Esri, 2017). The user-friendly interface was revealed in the removal of dialogue boxes that would cover the project being worked on, instead there are panes to the side, so work could continue whilst waiting for the function chosen to execute (Esri, *ibid.*). There is also the additional ability to swap between several projects at once with tabs across the top of the data frame (Esri, *ibid.*), meaning, for example, a 2D project of Arbor Low was open alongside a 3D visualisation of the same or different data of the site. The user interface also allowed for the clear finding and importing of data from other sources and files, such as orthomosaic images and DEMs created inside Agisoft to begin analysis and visualisation in 2D and 3D. These DEMs are created as part of the methodology, therefore, researchers do not need to download a dataset, or use DEMs that are not focused on a single area. The DEMs are generated from the aerial photogrammetry and used within GIS software to edited as needed.

Through the use of GIS software tools such as *slope, hillshade* and *cut/fill* the areas of concern can be can clearly documented and displayed in a variety of visualisations. The data can be altered by using the *clip* tool to remove extraneous features such as drystone walls or fences that would influence results, and it allowed for focus to be put onto the site alone, without other manmade features that do not relate beyond being a field boundary or to demarcate an area of concern, like at Pilsbury Castle after a landslip required a partition to allow for grass to retake, as per the PDNPA.

The visualisations from all sites could be highly useful for bodies that are charged with the care for these monuments. They can be used as part of a longer monitoring period of a site of concern, and aid in spreading awareness of damage to heritage earthwork sites to the public in a simplistic yet clear fashion, as suggested by Muenster (2022), in the form of knowledge carriers, tools for research, and representation across a few decades. As heritage sites are part of the value of a landscape, they can be as susceptible as other landscape features to damage, both natural and anthropogenic.

Since earthwork monuments are considered integral parts of a landscape’s character value because they are part of the historicity factor (Tveit *et al.,* 2006), then monitoring and preservation are imperative in order to manage site health of culturally valuable features. Alongside the cost-effectiveness of UAV derived aerial imagery, and creating high-resolution orthomosaic images and DEMs, the analysis and visualisations of this data would be extremely useful to NGOs that care for heritage sites as they could monitor them with relative ease for research purposes and understanding, create databases of digital, photorealistic models of heritage, and hypothetical reconstructions if wished in order to present a site in the theorised appearance of a site. These latter two aspects would be particularly beneficial in regard to the dissemination and the raising of public awareness of their sites and landscapes, by being utilised on modern and accessible platforms.

6.3 Digital Models for Public Awareness, Interaction with and Access to Heritage

Culture has an integral role in world economies, particularly urban ones (Alboul *et al.,* 2019); cultural heritage is a landmark and a source of pride in communities that live nearby, for example Pompeii, Italy and Ironbridge, United Kingdom (Alboul *et al., ibid.*). It is part of the ecosystem of a place and is often considered a window into the past, and with dangers towards heritage being pronounced across the world despite protections in place, modern spatial technology provides new approaches to how these heritage sites can be preserved and protected, and can be used to reach the public in new ways (Alboul *et al., ibid.*). It also allows researchers in archaeology and similar disciplines to approach the past in relation to the modern world in novel ways of study, and understanding of past and present (Cerato and Pescarin, 2013). Vital to any conservation process is the identification of the heritage site, its current state and the propagators of deterioration and damage (Bassier *et al.,* 2018).

The outcomes of this investigation could be utilised in a variety of ways, particularly the digital 3D models, as they can be imported into platforms that can reach out easily to the public to help them engage with, and to understand heritage sites around them, how they are threatened, and to aid people who cannot access sites. Muenster (2022) did state that a distinction should be made between a 3D digitization of an extant feature that is the source – in this investigation, the contemporary DEM – and a 3D digitization where the object or feature is envisioned through other sources that describe it, such as planning documents that outline destroyed, altered or never-realised construction.

3D reconstruction of heritage is becoming incredibly important over time as part of heritage health, conservation, research and accessibility (Muenster, 2022). In that same investigation, Muenster (*ibid.*) stated that a main distinction of purposes of 3D modelling is between preservation, education and research, but that they can be, and are, interlinked. The need for three-dimensional reconstruction was because two-dimensional GIS maps were not enough to represent the complexities of a landscape completely (Cerato and Pescarin, 2013). 3D, on the other hand, can do that more effectively, as even though landscapes can alter dramatically, information from archaeology, ecology, remote sensing, historical geography and geophysics can still be integrated into GIS (Cerato and Pescarin, 2013). The interactive implications have become more prevalent in the scientific community, and can play an imperative role in support of scientific discussion amongst experts, and coupled with the aims of the common user, brings the past to a broader public audience in the form of Virtual Reality (VR) in museum exhibits (Cerato and Pescarin, 2013). Through landscape analysis, the use of remote sensing, and several other disciplines, a full range of aspects can be highlighted (Cerato and Pescarin, 2013).

When the rise of computer visualisations began in the 1990s, many of the studies of the time worried that outputs would just be attractive, pretty imagery akin to those in fantasy games (Reilly, 1991; Miller and Richards, 1995; Sims, 1997), and such reservations still exist (Sanders, 2014). Shanks and Tilley (1992) questioned the use of reconstructions as a means to interpret a site; they had reservations about public consumption too, suggesting that it risked the potential of the public to view them as fantasy, clouded by nostalgia and mythology. Galeazzi (2018) also queried if reconstructions were an original representation of heritage or virtual fakes. Then there were also concerns over the hyper-realism in virtual reconstructions at the start of the 21st century when virtual technologies became more popular in heritage research (Falconer *et al.,* 2020). It particularly focused on constructions being formed and created on unclear evidence, and potentially lacking in an agreed protocol for demonstrating intellectual transparency in use, construction and design of virtual rebuilds (Falconer *et al., ibid*.).

There are reasons as to why, as part of this investigation, 3D documentation and dissemination of heritage is considered to be important, not only for research but to spread awareness and understanding of heritage around them, to allow people to interact on platforms and in ways that are available today, and to provide a kind of access to those not able. As Kosmas *et al.,* (2020, pg. 473) explained, *"…the goal of acting as educational tools for the promotion of CH (cultural heritage) in a pleasant manner, by presenting stories in which the users are immersed, providing a vivid and engaging experience."*

As aforementioned, to many experts since the introduction of digital heritage to present day, such as Sanders (2014), this type of vivid experience in the digital form is not favoured because it takes away from the reality of a site, but if done with transparency and the understanding these are interpretations of heritage – they are ultimately hypothetical – then there is more to be gained from it.

6.3.1 Challenges of Digital Heritage and Dissemination via Virtual Reality

VR has been applied to cultural heritage for the last two decades, and as technology advances, it is becoming even more useful for research and public use (Alboul *et al.,* 2019). The grasp VR has is increasing as it can reach the public far removed from the site (Cerato and Pescarin, 2013). It preserves site records and can aid in reconstruction of damage or destroyed sites, and could aid in the analysis of what led to the current state of the heritage site (Alboul *et al., ibid.*).

Despite these potentialities, researchers have been somewhat hesitant to utilise VR, largely due to the degree of uncertainty and the level of subjective imagination that may be used in order to reconstruct heritage that inherently does not exist complete (Unger *et al.,* 2020). Though there is a need for reconstructions, Cerato and Pescarin (2013) did recognise that landscape reconstruction is a difficult and challenging activity, and there is an implication of managing high levels of uncertainty, which requires several disciplines to cooperate, and landscapes change or completely disappear over time (Cerato and Pescarin, 2013).

Technology has led to an era of photorealistic rendering, but as technology advances, there is apprehension about the preservation of the data (Champion, 2017). Hard- and software used today will become obsolete, and the data used and created may not preserve as well as digital heritage outside of it. Champion (2017) acknowledged this is a concern, but the real issue was the lack of suitably maintained infrastructure. In a rather oxymoronic way, as Champion and Rahaman (2020) described it, there is a lack of preservation of the software and the 3D models themselves as technology advances, which Champion (2017) also acknowledged; a lack of global metadata, a systematic pipeline featuring open-sourced software, a lack of community reviews, and critiques that augments and maintains content. The showcases that acted as platforms of new technology are now defunct such as *Rome Reborn* and *Beyond Space and Time* that have been taken offline, used proprietary software, or disappeared due to a lack of maintenance long-term (Champion, 2017; Champion and Rahaman, 2020). Many are inaccessible and the online existence was incredibly short (Doyle *et al.,* 2009;). As a result, there are few existing examples to learn from.

In 32 charters focused on cultural heritage, Statham (2019) found that merely two focused on broad scientific guidelines for virtual and visualising heritage. These are the London and Seville Charters, but both are high-level principles more concerned with authenticity and scientific rigour (Statham, 2009; Falconer *et al.,* 2020). The London Charter sought to have ground rules for visualisations, in order for there to be greater liberty, the methodology has to be precisely recorded, be transparent, for researchers; an aspect of a building may be visualised, but without considering and informing that it is a part of a larger whole, the visualisation is incomplete – this is a “hypothesis machine” (London Charter, 2009, pg. 68).

Unger *et al.,* (2020) acknowledged there are risks to using VR to present heritage; as archaeology and the sites involved are inherently incomplete, and the interpretation is ambiguous. This leaves visualisations with a high degree of uncertainty – this uncertainty being why some researchers do not always fully believe that VR should be used to any great extent for reconstructions of heritage sites. The London Charter does specify that reconstructions should be accurate in determining the differences between real data and hypotheses, and levels of probability (Unger *et al.,* 2020).

Ch'ng *et al.,* (2017) commented that though VR is becoming more mature - enough to facilitate experiencing virtual heritage - it is unclear where the field is in regard to how well the research community and institutions are doing with the technology. Falconer *et al.,* (2020) recommended that research may need to focus on characteristics of successful simulations with a need to create guidance on how exactly 3D platforms and immersive technology can be used best for public interaction and engagement.

6.3.2 Benefits of Digital Heritage and Dissemination via Virtual Reality

The main positive for VR is that it opens to a computer-literate generation that frequently use virtual spaces, wherein the virtual representations are not as expensive physical representations, and the maintenance costs of mobile applications is near to zero (Unger *et al.,* 2020). There is a wide range of free 3D modelling software; for example, SketchFab, that can be used to display 3D reconstruction data free of charge in augmented reality (Unger *et al., ibid.*), and these utilise Digital Elevation Model data to present the height and depth change across a site.

Unger *et al.,* (2020) said the biggest challenge of presenting very early human culture is that the cognition is focused and encapsulated inside the highly professional world of archaeological monument care and particular research projects, therefore making the knowledge accessible virtually is desirable for artefacts and entire sites. It has the benefit of being easy and fast dissemination of information on widely and commonly used platforms such as smartphones via the internet, which is largely available to most (Unger *et al., ibid.*). 3D models have been used in education for illustrating and teaching history inside museum exhibits, in games or television (Ott and Pozzi, 2011), and whether ICT can provide additional value to cultural heritage. They also called for more interdisciplinary approaches in cultural heritage (Ott and Pozzi, *ibid*.). Muenster (2022) also outlined that teaching is also achieved using digital competencies via heritage, and 3D VR environments can foster more user participation and if used within gaming, more immersion and exploration of large data resources in real time (Kosmas *et al.,* 2020).

A possible approach that Unger *et al.,* (*ibid.*) described is projection into photorealistic models of an actual heritage or archaeological site obtained by laser scanning or by photogrammetry, as it would be possible to distinguish existing structures and those built based on interpretation. With easier access, the role of VR has moved on from being complementary in nature to being part of the interpretative process of data; obviously such a process does garner a level of subjective imagination yet virtual visualisation can quickly and clearly determine boundaries between attested, anticipated and imagined features and aspects of sites (Unger *et al., ibid.*). Therefore, it is critical that there should be supplementary metadata that can explain reconstruction steps and interpretive methodology – this could make visualisation a standard part of the research process (Unger *et al., ibid.*). Reconstruction and interpretation is crucial in making it accessible for the public, and using digital platforms and VR can only strengthen the potential, as an image is typically comprehensible where text may fall short if the reader has no understanding.

VR has also been engaged in cultural tourism due to the characteristics that enable tourism to reach the goal of providing tourists with a unique and enhanced experience, but VR also reduces the barrier of distance between potential tourists and the destination by educating them on the intended holiday spot ahead of the trip (Bruno *et al.,* 2010; Kim and Hail, 2019). However, though the interest in VR is increasing, it does not have the same following that videogames do, and they are not as commonplace as other media platforms (Champion, 2017). The introduction of Head Mounted Displays (HMDs) such as the Oculus Rift means that VR is slowly becoming cheaper and more accessible, but still do not deliver what they promise (Champion, 2017). However, the consumer market for VR, both hard- and software, is expected to be worth over US$16.3 billion globally by 2022 (Lee *et al.,* 2020).

Champion (2017) focused on what the digital technology is for: the audience. Champion (*ibid*.) proposed to UNESCO for a Chair of Cultural Heritage and Visualisation to help develop infrastructure and repositories of 3D heritage models for improved access by the public. The intent is to survey and collate existing world heritage models, unify metadata schemas, determine the most appropriate 3D format for online archives and web-based displays, provide training material for free, and demonstrate ways to link 3D models and subcomponents to relevant sources online (Champion, 2017).

Champion and Rahaman (2020) reviewed several online repositories for 3D heritage and despite this increasing number, few academic papers review what is available, and there is a lack of explanation as to how the assets and their functions can further the field of digital heritage and aid in preservation, documentation and promotion of real world heritage. Various charters, for example the London and Seville Charters, have declared the success of virtual heritage (VH) and that these projects depend on models and associated research content (Scopigno *et al.,* 2017; Tucci *et al.,* 2017; Champion and Rahaman, 2020). The charters have stipulations as to how online repositories of 3D heritage models operate, but few projects address the charters in regard to access, use and reusability, and preservation (Champion and Rahaman, *ibid.*). As a result, six criteria have been suggested to measure the usefulness of several online 3D repositories, and 13 key features were also recommended as useful additions (Champion and Rahaman, *ibid.*).

As technology advances, software and technology have allowed for the improvement of user experience for those who visit museums, archaeological sites, and exhibits (Champion and Rahaman, *ibid.*), and there is an impressive amount of material produced in digitization projects in the last decade (Scopigno *et al.,* 2017). There is now more modelling software for researchers, hobbyists and scholars to utilise as well (Champion and Rahaman, *ibid.*). Ideally, all this new software should open up new avenues for documentation and preservation, however Champion and Rahaman (*ibid.*) argue it does not: there are issues around reliability and robust 3D data formed on standard file formats, comprehensive and consistent metadata, information on acquisition processes, and copyright. There is also the issue of a lack of long term preservation of the actual 3D models, their use and reuse in education for student learning and wider public dissemination (Champion and Rahaman, 2020).

It cannot be ignored that 3D models can be vital in understanding and interpreting archaeology and heritage sites; they are important for scholarly research and publication, they provide data and evidence, yet communicating their value needs to be helped with better infrastructure (Champion and Rahaman, 2020). As charters have declared the success of VH with 3D models, there needs to be better safeguards for 3D models in order to promote and disseminate real world knowledge and understanding, and yet the recommendations of these charters are not commonly addressed by 3D heritage infrastructure (Champion and Rahaman, *ibid.*). Museums initially were hesitant to use VR in their exhibits, however the use has modernised museum displays; it is now commonly used for storytelling, education, restoration and conservation (Alboul *et al.,* 2019).

Koller *et al.,* (2009) advocated for a centralised digital archive system that was open access of scientifically authenticated 3D models based upon scholarly journals, and with standard mechanisms of preservation, peer review, publication, updating and dissemination. However, Koller et al., (*ibid.*) also knew this realisation required many research related issues first be addressed. There are over 50 commercial repositories for model download, sharing and trading (Übel, 2019), and the number of 3D heritage models grows, particularly non-professional ones (Pfarr-Harfst, 2016). Champion and Rahaman (2019) determined that data reliability, robust file formats, accepted metadata, integrated paradata and accessible information on copyright were highly problematic issues that hindered archiving and wider dissemination of 3D heritage; the digital domain is rich and complex (Scopigno et al., 2017). The GLAM sector use differing types of visual media in their studies, analyses and interpretations, and 3D models are one of the imperative media types to display and document the importance of cultural heritage and their value (Champion and Rahaman, 2020).

Koller *et al.,* (2009) advocated for the creation of central services that followed general models of a scholarly press but also photographic archives. The former offers quality control methods, creator recruitment, and outreach to other academics, and the latter offers methods for economies of scale, sustainability via aggregation, and revenue sharing between those who create and distribute (Koller *et al.,* 2009). Therefore, it was suggested that a long term target should be open repositories of scientifically authenticated virtual spaces, meaning that only 3D models created by those with appropriate qualifications, clearly identified with published metadata should be accepted (Koller *et al.,* 2009).

Once archiving and access to 3D data is assured, the following step is to evaluate visibility and exhibition proficiency of the host site (Champion and Rahaman, 2020). Features commonly offered by 3D model viewers include:

- Zooming in and out
- Rotation
- Movement e.g. walking
- Add or remove sections of the model
- Wireframe and texture view

- Screenshots
- Annotation
- Change field of view
- Measuring
- Range of file formats for download
- Timelines
- Embedding

Not all the reviewed 3D model repositories have these features, as outlined by Champion and Rahaman (2020), and institutional repositories do not allow general public to upload 3D models; instead they offer free services with downloads, yet file formats are restricted, and it does not appear that 3D models have a Digital Object Identifier (DOI) either to ensure permanent identification (Champion and Rahaman, 2020). In their investigation, it appears – of repositories included in the review – few had the ability to 'walk around', which would be highly useful for both the public and researchers; the software CARARE allows a viewer to walk around, but changing field of view is only allowed by SketchFab and 3D Warehouse; zoom and rotate – another highly useful tool - is allowed by SketchFab, 3D Warehouse, Poly, p3d.in, GB3D Type Fossils, CARARE, and Smithsonian (Champion and Rahaman, 2020).

CARARE uses 3DPDF – this embeds a 3D model into a PDF – HeritageTogether, a crowd-sourced heritage platform created by Miles *et al.,* (2015) used 3DPDF as a method of interactive heritage with the general public. In their investigation, Miles *et al.,* (2015) found 3DPDF were highly useful teaching tools for including site information to the models, and although software that enabled 3DPDF at the time had not been developed greatly, the prevalence of PDF as a format allowed for easier dissemination to the general public. However, there are vulnerability and security issues associated with PDF, and a need to function on low-end browsers on mobile technology, models published with *HTML5* and *WebGL* are popular alternatives (Champion and Rahaman, 2020).

Europeana however, does offer the ability to search by media type and links are given to external hosting sites (Champion and Rahaman, 2020); clearly there is no standardised way of publishing and holding 3D models for the long run, and this impacts on the usability and the usefulness of the models, and the ability to disseminate raw digital data is more a wish than reality (Scopigno *et al.,* 2017). The issue is the growing number of 3D visualisations – both scans and reconstructions – that are shared with the public online using platforms that were not originally designed to host heritage in such ways - therefore fail to provide context (Statham, 2019).

It has been suggested a real-time viewer that displays a dynamic model, which can rotate the viewing position, would be advantageous (Calin *et al.,* 2015; Sullivan, 2016). Sullivan and Snyder (2017) emphasised the human experience of making meaning, and pedestrian level 3D navigation and real-time interaction are highly important for research. Other studies have also suggested typological annotations and visualising changes in a building or a component over time (Pauwels *et al.,* 2008). Human object interaction is imperative in 3D visualisation (Galeazzi and Di Franco, 2017), and they also argued that links should be made to other databases to provide suitable access to researchers.

Champion and Rahaman (2020) reported that there is an issue with how and where the data is collected from and with access; 3D model viewer CyArk provides free access to high-resolution 3D data – with point cloud and photogrammetric imagery – but prior permission is needed to download any data – and this prevents access to datasets that could be used by others for further research. According to Champion and Rahaman (*ibid*.) it is difficult to find specific 3D models and related information as the majority are not connected to external sites or portals with information.

Though there are guidelines on VR and heritage, Statham (2019) stated that International Council and Monuments and Sites (ICOMOS) and UNESCO heritage suggestions are not the main drivers of commercial solutions, like SketchFab, and the supporting documentation is often partial and insufficient. Plans currently favour solely preservation and not reconstruction, which is understandable considering the need to preserve authenticity – despite the flexible definition – and to remain non-intrusive (Statham, 2019). Any reconstruction must be based on historical evidence, and only on hypothesis where absolutely necessary, and these uncertainties must be documented and communicated (Koller *et al.,* 2009); however, by creating a digital reconstruction, this should aid in hypothetical rebuilding off-site, and researchers may be able to hypothesise and experiment easier with particular forms of gathered data (Statham, 2019). In their investigation, to promote the rigour required by the London Charter, but to recreate a stone alignment that was no longer known nor present, Falconer *et al.,* (2020) used a range of sources –antiquarians, older excavation documentation and modern geophysics – in order to present a reasonable and scientific recreation of the former stone alignments at Avebury, Wiltshire.

The intent of this investigation was to do the same at each of the four sites, particularly with the Bull Ring as it has faced serious destruction due to lack of preservation and protection from NGOs, and its location within a mile of the local quarrying industry. If Arbor Low, which Bull Ring most likely resembled, can be rebuilt using contemporary data and archaeologists' estimations, then the same theory can be used on the Bull Ring to depict a scientific estimation of how it once appeared: a drastically different henge than what is observed today.

6.3.3 Digital Heritage and Dissemination via Videogaming and Serious Gaming

Champion (2017) argued that there is a great divide between serious games masquerading as entertainment, and the motivations and aims of archaeology. Champion (*ibid.*) believed there were very few cases of success that were ultimately shareable with clearly delivered outcomes, so the question is posed as to why games have succeeded where VR has not?

Despite the statement by Alboul *et al.,* (2019) that VR has been in-use for the last two decades, it neglected to mention the quality of the technology in full; Champion (2017) asserted that early modes of VR were commonly low resolution, unreliable and needed very specific equipment to function, which is still the case, but is not so for non-VR videogames. The major difference is that videogames are often very polished, focused and allow for the layman to 'mod', in other words change, games to their own wishes and desires (Champion, 2017).

Games have a very loyal following that allows for more and better feedback to companies that create these commodities, and the fan-bases often create grassroots marketing for companies (Champion, 2012; Champion, 2017). VR does not have this same following; whereas game consoles and computers are found in nearly every household, VR technology is not.

There are affordances provided by games that VR does not: feedback, themes and rewards, they follow particular genres, they challenge the user rather than spoon feed them, which has been a noted annoyance of users in regard to VR, and games offer procedural knowledge, compared to the descriptive and prescriptive knowledge in VR environments (Champion, 2017).

There are negative preconceptions about games as a whole, which Champion (2017) outlined as follows:

- Puerile wastes of time

- Only for children
- Only about fantasy
- Violent

There are games that are directed to younger audiences, however, video-gaming is also targeted at adults, and the conception of them only being for children and a waste of time conveniently ignores the common pastime of watching sports (Champion, 2017). James Gee argued that games can be used as a platform for learning, and UNESCO stated that games could provide assistance in promoting heritage to young people (Champion, 2017).

Serious games have been used by the US Army as early as WWII in order to improve their appearance to the American public during the war, but it has now branched out over the decades into education, health care, and cultural heritage (Laamarti *et al.,* 2014). In cultural heritage, using basic consumer machines, there is real-time interactive visualisation of historic sites, museums, and realistic virtual heritage scenarios. Laamarti *et al.,* (*ibid.*) also acknowledged that serious games in heritage studies operated differently, as they are used largely as a preservation strategy.

Laamarti *et al.,* (2014) used three classes for cultural heritage serious gaming: reconstruction of history, cultural demonstrations, and virtual museums. From that same investigation, Laamarti *et al.,* (*ibid.*) said "cultural entertainment" games from the 1990s were favoured such as *China the Forbidden City* in 1998, *Versailles 1685* in 1997, and *Rome: Caesar's Will* in 2000. Cultural demonstration games educated people about traditions, beliefs and social values through techniques such as storytelling, such as *Never Alone* (*Kisima Inŋitchuŋa*) in 2014, created by the non-profit Cook Inlet Tribal Council (CITC), a game that followed oral storytelling traditions and values of the Iñupiaq, using the Kunuuksaayuka story of a girl and her fox who overcame obstacles to save her people from starvation in a blizzard (Cook Inlet Tribal Council, 2017).

It became the first game of a new genre called ‘World Games’ (Cook Inlet Tribal Council, 2017); an avatar was guided through levels whilst solving practical problems and creatively overcoming challenges, and played completely in the Iñupiaq language with subtitles. Upon release on 18th November 2014, it was an instant hit with 2.2 million downloads, in over 750 articles, glowing reviews in Time Magazine, The Guardian and others, rated 4.5 stars out of 5, and won a BAFTA for ‘Best Story’ and ‘Best Debut Game’ (Cook Inlet Tribal Council, 2017). Everything was done to match and be part of their culture and knowledge, to avoid looking like a Disney cartoon, and not being true to their values as a people. This is where the concerns of fantasy in videogames can arise.

Fantasy has been an aspect that has troubled archaeological researchers (Reilly, 1991; Miller and Richards, 1995; Sims, 1997; Sanders, 2014). Fantasy and violence was a common critique of videogames, but some of the best-selling games and game franchises are not overtly violent nor based solely on it, including *Minecraft*, *The Sims*, *Mario*, and *SimCity* amongst others (Champion, 2017). Yet fantasy is considered a key component in games by experts in Human Computer Interaction (HCI), it is incredibly popular in literature, and it provides a series of affordances – it essentially allows imagination to fill in the gaps! (Champion, 2017). However, many studies have not welcomed this possibility, as many worried that the attractive images made were akin to fantasy gaming (Reilly 1991; Miller and Richards, 1995; Sims, 1997; Sanders, 2014). It is perhaps best to term fantasy as ‘thematic imagination’: there is a known behaviour toward fantasy games, and it induces narrative coherence and can convey mythologies that are connected to historical sites as a result (Champion, 2017), essentially that which is ultimately intangible. Serious games have several definitions:

- Any game produced using gaming software could be considered a serious game (Alvarez and Michaud, 2008)

- A serious game is simply a computer based game and the classification is a marketing tool only (Sawyer and Rejeski, 2002)
- The most common definition is a game that does not have entertainment or enjoy as a main focus (Michael and Chen, 2005).

According to Laamarti *et al.,* (2014), the most common definition given to serious games was that they have an element of entertainment (Zyda, 2005; Alvarez and Michaud, 2008; Jantke, 2010). They also have the ability to enhance a user's experience through multimodal interaction, and this can be in differing contexts such as education, health, and training (Arnab *et al.,* 2011; de Freitas and Liarokapis, 2011). Most research agreed that digital serious games utilise different media in one, combining graphics, text, animation, audio, and haptics. Laamarti *et al.,* (2014) also believed that the term "serious" comes more from the message or input intended to be taken from the experience, rather than meaning there is nothing enjoyable about the game, meaning the user is exposed to an environment that delivers knowledge, a skill or message from experience (Lin *et al.,* 2006; Yim and Graham, 2007; Consolvo *et al.,* 2008; Arnab *et al.,* 2011; Orozco *et al.,* 2012). This experience is related to specific context of serious games such as health and education; Laamarti *et al.,* (2014) defined serious games as an application encapsulating three aspects: experience, entertainment and multimedia. Since 2004, the use of serious games in industry has grown from less than 100 to over 200 by 2018, and at by 2014 it was over 300 and growing (Laamarti *et al.,* 2014). In 2010, it was estimated that the serious games market would likely keep growing rapidly and reach a value of €10 billion in 2015 (Michaud, 2010).

Whilst gamification could be a commercial saviour for educational game designers, there are critics: Fuchs (in Champion, 2017, pg. 26) was said to have explained gamification as the "*use of game-based rules, structures and interfaces by corporations to manage and control brand-*

communities and to create value"; this definition reveals the attraction and derision received (Champion, *ibid.*). Another more technical based critique is the low quality of images, movies and real-time interaction, and game engines and environments challenge anything made in CADD (Champion, *ibid.*) – however, progress overall of computer graphics and the quality of imagery from UAVs is a challenge to this concept, and this investigation wishes to put forward this argument. The imagery is used to create high quality 3D models of heritage sites; UAVs' aerial image quality may not be the best possible when doing expansive areas, however they do very well when used on particular sites, especially those in open grassland (Bollandsås *et al.,* 2012), where it is comparable to LiDAR-derived imagery. Statham (2019) researched five platforms, one being gaming engines, that offered features facilitating scientific rigour and community participation based on guidelines from ICOMOS and UNESCO, which are not the biggest commercial drivers for such platforms.

Today's game engines offer a high level of customization and format, art and programming skills are all down to the creator, and thus a limit to how extensive it can be used (Statham, 2019). Other resource limits such as costs, deadlines and team size all impact the use, but game engines such as *Unity* and *Unreal* – two of the most popular engines used for 3D visualisation – can be used without costs and support 3D content, virtual reality and Alternative Reality (AR); *Unity* is very popular with researchers as there is pre-available content that costs little that can be used to flesh out the scene, and is compatible with iOS, Android, PC and the web (Lužnik and Klein, 2015; Statham, 2019). For example, Falconer *et al.,* (2020) used contemporary LiDAR data and modified it to replicate likely topography of Avebury 2300 BCE, and used open source *Terrain Builder v. 1 in the Fieldscapes ™* platform, built in the game engine *Unity 3D*. The stones that remain, alongside side other finds, were created and exported in Collada (.DAE) format, are publicly available, and the stones that no longer exist were created based on those that do.

Though large scale projects likely can afford better output from gaming engines, even small teams can create impressive game scenarios, but this does not mean gaming engines are the solution - due to the high degree of flexibility, it is an attractive potential and as they are an executable file instead of being embedded into websites, they can be used far more often and into the future, particularly on computers (Statham, 2019). As documentation and representation of heritage sites is rapidly growing and evolving, with advancements in remote sensing, more heritage projects wish to integrate innovative sensor data into workflows and make use of the more complex analysis tools newly available to create highly detailed outputs (Bassier *et al.,* 2018). There is a gap in how to transfer outputs from the innovative data acquisition to something useful for analysis, and current procedures may be restricted due to proprietary software or knowledge requirement (Bassier *et al., ibid.*).

6.3.4 *Accessibility*

Though there are many potentialities of digitising and virtually modelling heritage, there are experts who worry about the loss of realism. Yet, there are those who cannot enjoy a heritage site at all: individuals who have physical disabilities, individuals with mental health issues and struggle to leave their homes without preparation beforehand or at all, individuals with illnesses that cannot leave hospital, those who cannot financially afford the travelling, and people of colour who may not feel able to access these places due to racism.

Majewski and Bunch (1998) argued that only when those with disabilities are accepted as an influence that contributed to the past, present and future would the need for museum accessibility be fulfilled; it is more than ramps, appropriate bathrooms and multi-floor access, it encompasses all disabilities, both visible and not. As much as there is the argument that models of heritage lose realism and invite the fantastical, a person who cannot see the site at all, loses everything. Disabled people who travel are a commonly forgotten market segment in tourism

(Huh and Singh, 2007). VR could facilitate access for some disabled users, but for physically disabled people in particular as they often face a range of landscape difficulties, transport issues and negative attitudes (Guttentag, 2010).

Current technologies and advancements are enhancing access for disabled people and other socially isolated groups to cultural heritage environments (Kosmas *et al.*, 2020). Museums, archaeological sites and libraries utilise technology to foster engagement, despite initial scepticism that attention may move from exhibits to the interactive installations, and that results would be controversial (Kosmas *et al., ibid.*). However, interdisciplinary research has led to joint outcomes in the form of scientifically accurate visualisations of heritage when cultural heritage experts and scientists have come together (Kosmas *et al., ibid.*). Katie Green of the Grantham Journal (2022) recently published a newspaper article on the use of VR in a Grantham, UK care home that allowed residents to visit places they'd always dreamed of, such as the Northern Lights in Norway, the Caribbean and even space (Green, 2022), and the owner of the company that offered the trial to the care home stated that VR can be used as a “getaway” for those who are in isolated environments.

As aforementioned, disabled tourists are commonly ignored in the tourism sector, but in some situations, stakeholders and other responsible parties (i.e. NGOs) are able to alter sites to aid those who are physically disabled, but this cannot always be done at heritage sites where conservation is required (Goodall *et al.,* 2004). For instance, the upstairs floor of Shakespeare's birthplace in Stratford-upon-Avon has a VR exhibit installed on the ground floor for those who cannot easily access it (Goodall, *et al.,* 2004). To alter the house would not have been appropriate so it was not possible for wheelchair users to navigate. In the Peak District, Hails (1997) recognised that a weakness of Arbor Low and Gib Hill was the difficultly for elderly, disabled and those with pushchairs to access them, yet retrofitting or alteration cannot be easily done, if at all, for heritage sites situated in the countryside or National Parks such as the Peak

District due to landscape factors, considering the environment in which they are situated. Since 1997, a hard pathway has been put in place at Arbor Low and Gib Hill up to the gateway into the first field, so there has been alteration where possible. In both the Peak and Lake District national parks, however, there are groups set up for blind walkers and hikers that have sighted guides (Macpherson, 2009), so if retrofitting or alteration cannot happen at largescale, then sighted guides in walking groups may be of assistance at sites like Arbor Low and Gib Hill.

On one hand, there is merit and benefit for those who cannot visit sites in-person. Such limitations placed on people, and for those who are disabled and cannot reach nor explore outdoor environments easily, advocates for the use of virtual reality in heritage, and not only for preservation and documentation, an opinion reached during this investigation. Whilst there is not a panacea for every disability, for example, digital online resources would be of benefit to those who are wheelchair users and others who struggle with physical accessibility, but it does not work for those who are blind or have vision impairments. It is easy to forget that studying landscape is not accessible to those with partial or no vision (Macpherson, 2009), even if Jackson (1984) defined landscape as something that can be understood and comprehended at a glance. For those who have sight impairments, Macpherson (2009) found that a participant interviewed used not only what her current sight condition is or her spatiotemporal location in the landscape, but also her memory of the Peak District, seeing both past and present landscape at once. Museums, such as the Museum of Modern Art in New York City, and the Guggenheim have tours of exhibitions in sign language for the deaf, or include touch tours (Cachia, 2013), but in that same investigation, Cachia (*ibid.*) said if instead of simply extending access, there is a need to question repressive norms that replicate hierarchies of visibility, ultimately asking what if museums rethink themselves as places of sensorial culture rather than solely visual?

Whilst those with physical disabilities that prevent or limit viewing a physical site in-situ would more likely benefit from digital and virtual heritage, it can also be used as a stepping stone for people of colour and those who cannot afford to reach these places. Access to nature is beneficial to mental health, and digital heritage is not about replacing the outside world with a hypothetical model of a site that is, by contemporary nature, incomplete (Unger *et al.,* 2020). However, due to the worries people of colour may have about being in these spaces, there is a long way to go for many to feel comfortable enough to even access these sites. The Council for the Preservation of Rural England (CPRE) released a study in 2021 on participant led research on access inequalities for people of colour. Many people of colour came from rural villages in their country of origin and once they arrived in the UK, they had to go right into jobs in the cities, away from, and therefore losing, their connection they had to the countryside (CPRE, 2021). Data from the Monitor of Engagement with the Natural Environment (MENE) reports by Natural England (2019), it was determined that only 11 to 15 % of black, Asian and minority ethnic (BAME) respondents went on holiday or spent time in greenspaces, compared to 38 % of white respondents, both adults and children, where only 20 % of children with a BAME background visited the countryside, whereas 40 % of white children did (CPRE, 2021).

Of course using digital or virtual heritage is not the cure for the lack of diversity in visitors to greenspaces, however, as quoted in the CPRE (2021) report, people of colour feel unwelcomed in these places as they are seen as white, close-knit and privileged, and displays of wealth exacerbated the unwelcome feeling as even simply souvenir buying was expensive for those in lower income brackets, both white and BAME respondents (CPRE, *ibid.*). Again, this investigation cannot speak any further on that aspect of the present barriers, but another concern was safety and possible racial abuse, but also a lack of knowledge of how to reach or access walking routes in the Peak District, for example (CPRE, *ibid.*). If a person or family does not know where they can go, they cannot access the heritage either.

Digital and virtual heritage, if displayed on websites, could be used in two ways: for those who cannot physically reach a site of interest due to disability, and those who would be concerned about how to visit, where to go and what they would be seeing. By having digital heritage, alongside maps, directions and ‘how-to’ information on reaching and visiting, it may aid in helping BAME individuals and families feel comfortable and empowered to visit as they would know ahead of time what they are going to see, where they need to go, and what amenities, i.e. toilets and cafes, are available and where, thus making areas like the Peak District, seen as white and conservative, become that bit more accessible.

Of course, this would be valuable as well for those with mental health concerns and disabilities, such as anxiety, who may feel they can also reach heritage sites because they know where they need to go. There have been calls to extend the Right to Roam and emphasis on the Countryside Code, informing people of their rights but also their responsibilities to the environment; Dennison (2022) acknowledged that a survey of visitors to the Lake District that only 13 % knew they should follow the Countryside Code. Information such as this, displayed alongside virtual or digital heritage could go a long way in making BAME families feel more informed of what to do, as well as any other groups of people who need the information.

It is beyond the scope of this investigation to cover the detail that is deserved for the topics of disability access and BAME individuals’ access to the countryside, but simply to suggest that 3D modelling of heritage sites could be used in ways to provide access to it, and to alleviate travel and safety concerns. It cannot, and never could, aid in other racially driven concerns such as verbal harassment or action.

6.3.5 Interaction via Digital and Virtual Platforms, and 3D Printed Models

Interaction is an important factor to prevail over; making people interested in using the alternative systems like videogames, VR and digital heritage, but also 3D printed models. Interaction can provide for different types of learning preferences and abilities, and modern, digital platforms may draw in the younger generations (Champion, 2017) or offer potential solutions to those marginalised by generic, non-intersectional methods. Those who would use these types of technology will differ too; Cerato and Pescarin (2013) defined two types of users in their research: common and expert. Common users' main aim is to understand the past, find joy, entertainment and affinity to increase knowledge. Expert users' main aim is to read a reconstruction and propose alternative possibilities of sites and landscapes.

As discussed in this chapter, Cachia (2013) stated that the Museum of Modern Art in New York City has touch tours for those with vision impairments, but museums should perhaps consider themselves as sensorial rather than solely visual. To attempt to address the sensorial aspect of heritage and landscape (though largely beyond the scope of this research), this investigation argues that 3D printed models may work in place of, or alongside, a digital archive. Neumuller *et al.,* (2014) agreed that with the enhancement of 3D printing would also enhance cultural heritage as part of a more multi-sensorial experience. A 3D printed model of either the contemporary site or a theoretical model could be used as part of tactile exhibits, so that blind or visually impaired individuals can 'feel' the site with their hands. These models could be scaled to give more pronouncement to the features of the site and could be part of larger exhibits that typically exist in museums and heritage centres already in the form of plastic models of sites, either artistically designed to imitate the past, or a close estimation to a current site. These new and modernised exhibits could then also be available online, which would allow for the disabled to view the site from their homes, and see the site in a way they may not have been able to before without difficulty (Alboul et al., 2019).

Conversely, Macpherson (2009)'s research revealed that those in a guided walking group in the Peak District did not necessarily want to touch things (i.e. grass, rocks, etc.) because it would "*look too blind*" (p. 1047). As geography should not be reduced to object or lone subject and must be considered intercorporeally – through other senses and other people – as it comes with other associations dependent on a person (Macpherson, 2009). So, this same concept could be applied to heritage within a landscape, either via tactile interaction or through enjoying the sight of their sighted guides and their own memories if they have them (Macpherson, 2017).

Regarding videogames and the long held belief that videogames and VR are only tempting to the younger generations, research by Falconer *et al.,* (2020) found that age did not appear to have had an impact. Participants in testing the virtual reality version of Avebury came from all age groups, therefore there should be no expectations nor conclusions jumped to regarding age. Nor should any be made regarding gender, IT usage and video-gaming, be it consoles, PCs or mobile phone and tablets. Falconer *et al.,* (*ibid.*) did note, however that older visitors needed a little more coaxing, but once they experienced the virtual Avebury, they had similar experiences to the rest of the participants, consequently any sites with a VR simulation may just need to alter how they encourage older visitors to use it.

Due to the London Charter (2009) requiring virtual models to be acknowledged as theoretical models, it could mean VR may impact on the notion of presence, the immersion and sensory input an individual would normally experience of the site in-situ. Presence is ‘the subjective experience of being in one place or environment, even when physically in another’ (Witmer and Singer, 1998). In research focused on immersion and gaining a sense of place in VR environments, Falconer *et al.,* (2020) focused on the site of Avebury, in Wiltshire, UK, and created a virtual environment, removing the modern day changes to visualise how it may once have looked when first constructed. Immersion was a key factor; Falconer *et al.,* (*ibid.*) noted that many respondents had similar emotional reactions – e.g. were absorbed – and answers were largely positive to the immersion used such as sound; it made it believable to at least some extent. No participant said it was ‘not at all believable’. The role of immersion in VR is a critical feature, even if it is considered a substitute for tourism; however Lee *et al.,* (2020) focused on the immersive environment’s role in authenticity and new museology – two major issues that museums face today – and the results of their investigation showed that immersive VR enhances the overall tour experience in a museum and induces the intention to physically visit.

When it comes to the serious gaming aspect of digital heritage, Inzerillo *et al.,* (2020) described serious games as “games with purpose beyond entertainment” in the expected sense, and stated they are highly useful tools for learning and skill development across many disciplines and domains. It can be used inside classrooms to entice students into learning and motivate them, but the process can be costly and slow (Inzerillo *et al., ibid.*). In light of the 2020 COVID-19 pandemic, that led to restrictions in leaving homes, online learning became more popular, and from there, some individuals took learning further: by creating virtual models of heritage and archaeological sites on platforms such as Minecraft (BBC, 2020). Lu *et al.,* (2022) also argued that due the tremendous impact that COVID-19 has had on the tourism sector globally and could take advantage of new technology for ‘virtual tourism’ (VT); that study concluded that museums are suitable for displaying virtual or digital heritage alongside in-house information in the traditional setting.

However, in that same study, some interviewees said they preferred using VT for cultural landscape (i.e. museum) over natural landscapes (Lu *et al.,* 2022). Marasco and Balbi (2019)’s investigation also had respondents say that VR should not replace an in-person, physical visit but be used to complement. Without context, this could be considered a marginalising statement, yet there is a level of truth, linking back to the London Charter (2009)’s requirement that the virtual models to be acknowledged as theoretical, that they are not the real site but are photorealistic, therefore are complementary to the actual site.

As Unger *et al.,* (2020) stated, many sites are inherently incomplete, and that is the same for sites in the UK and across the world can appear without context, abandoned if not wholly or partially obscured and destroyed; virtual representation may aid in understanding the decontextualized and obscured heritage (Falconer *et al.,* 2020). Virtual representation relies upon tangible spaces of today and intangible and imaged spaces of the past, but can become places in their own right (Falconer *et al.,* 2020). Fouberg *et al.,* (2020) quoted Yi-Fu Tuan as saying it is people who make places.

Once NGOs or other relevant stakeholders create or have access to digital and virtual models of earthwork heritage sites, both of the contemporary feature and any theoretical rebuilds of them, access to the public to enhance awareness and understanding is an advantageous path to follow, particularly considering the uses they can be used for. Also, considering the use of games for educational pursuits but recreating heritage sites, like Bryn Celli Ddu (BBC, 2020) and more recently Corfe Castle, rebuilt using a combination of historian and archaeologists' input, and a well-practiced gamer, the castle was brought to 'life', including building in the methods and styles of its long history (National Trust, 2022) (*see Appendix I)*.

Considering that the public has the ability to access information in a variety of ways, the next question is: how and by which method can these models and visualisations be used to reach a modern audience best?

6.4 Academic Uses and Outcomes of Digital Reconstructions and GIS Visualisations

Ultimately, the intent of the visualisations and volumetric analyses is to explore the effective use of UAV-derived aerial imagery in the documentation and possible monitoring need of earthwork heritage sites. Through the use of GIS software tools such as slope, hillshade and cut/fill the change could be easily monitored, documented and displayed in a variety of visualisations. The cost-effectiveness would be particularly valuable to NGOs that care for earthwork heritage sites.

Academically, being able to see a theorised archaeological height virtually – even when only theoretical – could enhance the understanding and possibly further research into more intangible aspects of heritage sites; Falconer et al., (2020)'s research at Avebury depicted this well; in that research, members of the public were immersed in a 3D environment of the henge as it could have sounded and appeared 2,300 years ago, with the intent to understand reactions and interest from the public in Virtual Reality models (Falconer et al., *ibid*.).

By creating theoretical models utilising both contemporary site data and archaeological estimations, digitally reconstructed models could be used as part of research to understand the intangible aspects of a physical site. Potentially, these theoretical models could add to the research Falconer et al., (*ibid*.) carried out focusing on believability of digital simulations of heritage monuments and complete sites. It must be stressed per the London Charter (2009) that modelling of heritage has to follow a transparent methodology using a scientific basis as it is the sole suitable and valid way to represent the past (Manžuch, 2017; Valle Abad et al., 2022).

A survey by Jones and McGinlay (2020) had 80.7 % of participants responding that they 'always' kept to public rights of way, a further 17.6 % admitted they did this 'most of the time'. In the same survey by Jones and McGinlay (2020), of 438 Peak District responses, 70 % of the respondents saw an increase in littering. Over time, this could become worse if left unchecked for the wider park, but also for earthwork sites, thus cost-effective monitoring would be invaluable.

Consequently, the visual comparison between the theoretical digital models displays this difference very well, and is far easier for general audiences to understand compared to presenting only tables of values that would not necessarily translate across. However, if used in conjunction, the volumetric values will have meaning and the damage far clearer again, aiding both researchers and the general public in understanding the damage, the potential causes, and what mitigating plans could be initiated by using visualisations such as these, and erosion rates could be determined with more certainty than previously, depending on the amount of knowledge of the lifetime of a site.

To improve, as has been said for Pilsbury, a multi-disciplinary investigation would benefit these sites, in particular Pilsbury due to complex nature. This approach was used by Halabi *et al.,* (2022) in their investigation on archaeological sites in Qatar in order to create a computerised system to aid in classification, representation and administration of archaeological finds in 3D reconstructions of artefacts.

The use of UAV-sourced imagery has been utilised elsewhere to positive effect, such as several places in Cyprus (Themistocleous, 2020), such as Nea Paphos Mosaics and Archaeological Park, Amathus Necropolis and Curium, all in Cyprus. In that research, Building Information Modelling (BIM) was used as well as SfM. Themistocleous (*ibid.*) determined that the uses of UAV-derived imagery were cost- and time-effective, non-invasive, and importantly, provide high resolution and high accuracy through the use of GCPs (Ground Control Points) as in this investigation, even with the marginal errors that are to be expected within such computer-based practices.

Current heritage projects struggle to provide stakeholders with the appropriate information, which is crucial – the data is required to be well structured and highly detailed for experts to make the correct decisions on assessment of sites, and gain understanding of recorded entities to constitute suitable treatment for preservation (ICOMOS, 2008; Bentkowska-Kafel, *et al.,* 2018; Bassier *et al.,* 2018).

Due to heritage sites being so exposed to natural and anthropomorphic hazards, and are sometimes within hard-to-reach areas, UAVs can reach these places, and then produce data that can be digitised and preserved. The aerial data is then used for feature identification, determining safe access pathways and for general monitoring of health at sites (Alboul *et al.,* 2019).

Beyond that, there are environmental factors that can limit or prevent access to researchers and visitors alike. Accessibility is required for any person or persons to visit or research a site, and accessibility can be prevented or impacted by seismic stability, artefact fragility, conflicts, deterioration of artefacts or sites, natural disasters, climate and visitor impact (Paladini *et al.,* 2019).

Chapter 7 Conclusion

This chapter will conclude the thesis. It will be divided into three main sections:

- Key findings
- Research direction
- Where it fits in research
- Uses so far

7.1 Key Findings

The main focus of the key findings is of the quality of the visualisations as it pertains to documentation, visualisation and monitoring capabilities for stakeholders and NGOs that have a vested interest in the care and health of heritage, and the volumetric analyses and differences. It will go by each objective as outlined in Chapter 1.

7.1.1 Objective 1

The first objective to achieve the overall aim of this investigation was:

- Combine UAV aerial imagery, Structure-from-Motion, and GIS to document four earthwork heritage sites

This was accomplished, as each site was recorded and documented through use of a DJI Phantom 4, Agisoft Metashape and ArcGIS Pro, as explained in Chapter 4. All the aerial data was of incredibly high resolution of between 1 and 4 cm, the alignment, dense cloud creation, mesh and total workflow of the modelling software resulted in outputs that were highly useful for use inside GIS software.

De Reu *et al.,* (2014) and others utilised very much similar methods, without the volumetric aspect, at active excavations as part of a documentation process running concurrently; Lai an Sordini (2013) also stated that this could very well become a standard documentation technique. Of course, as has been explained in Chapter 2, GIS has been used in archaeology for many years, but whilst being based off research such as de Reu *et al.,* (2014), Stek (2016) and O'Driscoll (2018), all of whom used UAVs, GIS tools, both alone and together, of features in the landscape rather than just active excavations, by combining the use of UAV, GIS, and SfM with tools originally designed for more geography and hydrology based research, the volumetric analysis concept added another depth to features in the landscape that may not have been as obvious, particularly because it is non-invasive, which for these tourist attractions is imperative, whilst also being important for site health and maintenance, which leads on to Objective 2.

7.1.2 Objective 2

Once the documentation of the first objective had been achieved, the documented material was needed to complete the second objective:

- Explore the use of GIS to visualise contemporary damage and calculate volumetric data of each site

This was also achieved. After the aerial imagery had been put through the Agisoft workflow and the outputs completed there, they were imported into the GIS software, ArcGIS Pro; this was the orthomosaic image (aerial photograph) and the Digital Elevation Model (DEM). Though was a slight issue revolving around the elevation heights, this was addressed by using the highest measurement and taking it away from all heights present, so the lowest measurement was 0 m, but the height difference across the site remained true to what is contemporary. Instead of exact height, relative height was used.

Once resolved, the modelled topography (MT) was the first stage of creation using the DEM height data; if volumetric data was to be calculated then a 'blank canvas' was required. Of course, any number of things may have happened in the field where Arbor Low is located, Pilsbury Castle or Gib Hill, and things have altered a lot around Bull Ring, but in order to establish what the contemporary data is, surrounding height data had to be used for this objective.

For all three sites that had an MT – other than Pilsbury Castle, as it was pushing the boundaries of the methodology as expected – the estimation resulted in a topography that was in line with what the area around each site could have been today had nothing been constructed. In the very least, it provided a base on which to begin possible monitoring checks over a period of time for site maintenance. From there, the contemporary site volume was calculated for Arbor Low, Gib Hill, and Bull Ring.

For Arbor Low:

- 2039.978 m^3 for embankments and barrow
- -1985.922 m^3 for ditches
- 174.866 m^3 for plateau
- 36.596 m^3 for ‘Avenue’

For Gib Hill:

- 1508.146 m^3 for round and long barrows
- -84.521 m^3 for all pits (combined)
- -58.677 m^3 for type H pits

For Bull Ring:

- 1215.670 m^3 for embankments
- 123.912 m^3 for plateau remnant
- -1472.177 m^3 for ditches and outer plateau

These numbers are in tables in Chapter 5 but are key findings as part of the potential basis that could be formed from using these measurements in order to monitor site health and document changes, if any, at these heritage sites, again as part of site health maintenance. It also tied in neatly with the following objective as outlined in Chapter 1.

7.1.3 Objective 3

Once the contemporary DEMs had undergone volumetric analysis, the use of the MT was required for the hypothetical reconstructions. The third objective was:

- Combine archaeological estimations and contemporary site data derived from UAV aerial imagery and GIS to hypothetically reconstruct the feature and calculate the volume of the hypothesised 'original' heritage feature.

All four sites had some kind of hypothetical rebuild, using Original Elevation (so named as it is original to this investigation) and Archaeologists' Estimation (named as other researchers' theorised heights and depths are used). The differences between the heights are important to the understanding of each rebuild.

Of all the sites, the Bull Ring has been the most threatened and damaged, particularly in more recent times. Due to often being considered as comparable to Arbor Low and the embankment there estimated to have reached 3 m, this was used for the Bull Ring; when compared to the Original Elevation measuring of 1.475 m, it resulted in a height difference of:

- 1.525 m difference between AE height and OE measurement

This meant that half the height has been lost if indeed the embankments were of similar height. As mentioned in Chapter 5, Barnatt and Myers (1988) had proffered a lower height at 2 m, and if that had been used for the hypothetical reconstruction, then that difference would have been smaller when compared to the Original Elevation measurement determined, which would still considerable. The central plateau was complex, because it combined into other sections of the henge, most likely because of the activity present for much of its history from farming and quarrying impacting this aspect, in both reconstructions and modern measurement. Also, the tree present in the centre which had to removed pixel by pixel, and given a new pixel height from a surrounding pixel just so any matching heights in the embankments would not be removed at the same time, thereby meaning that area of altered pixels isn't completely true to the height beneath the tree in reality, but the it had to be done in order to remove the tree and prevent from any anomalies in the calculation.

The volumetric analysis resulted in large difference in the embankment heights when both embankments were combined:

- 380.673 m³ for OE and 2020 DEM
- 949.73 m³ for AE and 2020 DEM

Again, possibly due to the level of damage, the east embankment was not joined to any other section of the henge unlike the west embankment, which combined with part of the central plateau. In many ways, the Bull Ring pushed the limits to the methodology like Pilsbury Castle did in other ways.

Pilsbury Castle was chosen because of the complexity present which meant the methodology would be tested, and because the headland was largely natural (Landon *et al.,* 2006), this meant determining exactly where the changes occurred to understand the extent of damage and further change over time was hard to pinpoint. The hollow-ways may have always existed or were created during the castle's construction. The main finding for this site was that interdisciplinary research would be beneficial to this determination, as it would require researchers with the subject knowledge to aid in a hypothetical rebuild.

Gib Hill, too, was complex in nature. Since the younger round barrow was superimposed onto the end of a long barrow, determining where one started as it merged was difficult, particularly for the hypothetical rebuilding of the long barrow. For the round barrow, the AE height used was very likely wrong or about another site completely, at 5.5 m from William Bateman in 1824 (Barnatt, 1989a), however the number was used to show what it may have looked like had such a height been true. A difference is more easily defined for the round barrow reconstructions, and the contemporary DEM as the long barrow is included in with the volume. The differences were:

- 306.385 m^3 for 2020 DEM and OE round barrow
- 3.176 m^3 for 2020 DEM and AE round barrow

Gib Hill has been fenced off from the wider field for some time, and though cattle have gotten through on occasion, the damage at the barrow site was likely from excavations in the past with some more recent as people visit.

Arbor Low is the best preserved of the two henges investigated, though there is damage present and it has suffered in the past. The difference in volume between the two rebuilds were:

- 705.793 m^3 for 2020 and OE DEM embankments
- -915.458 m^3 for 2020 and OE DEM ditches
- 23.593 m^3 for 2020 and OE DEM avenue
- 1544.706 m^3 for 2020 and AE DEM embankments
- -1533.701 m^3 for 2020 and AE DEM ditches
- 55.518 m^3 for 2020 and AE DEM avenue

These are key to Arbor Low because the history of the site has implied a level of safety afforded to it simply for where it is located. The land is pasture for grazing, it is walled off in a field and has seemingly remained that way for some time, as explained in Chapter 3.

7.1.4 Objective 4

The final objective this investigation was to discuss how this data and visualisations could be used:

- Discuss how the data could be used for further archaeological and geographical research, and to improve public awareness and access to heritage sites

Chapter 6 discusses these uses in far more detail which achieves this final objective, with commentary from other researchers who may and may not agree with digital heritage. The prior discussed key findings are beneficial to research and monitoring, but the digital 3D models and visualisations can be applied to increasing awareness of the public on heritage and the risks to them. To conclude, aligning well with *Section 7.2.3*, there are many possible directions that digital and virtual heritage could have in the public sphere regarding awareness, accessibility and interaction on platforms frequently accessed by the public.

7.2 Contribution to Research, Current Use and Possible Directions

The intent of this PhD was to utilise UAVs combined with modelling software and GIS in the monitoring, documentation and visualisation of earthwork heritage sites. This methodology of combining UAV aerial imagery, 3D modelling, and GIS based volumetric analysis techniques – from archaeology and geography backgrounds – highlights the ability to monitor earthworh heritage as part of site maintenance, and that hypothetical models of sites are possible. The key findings have provided a potential basis in site maintenance to observe changes in an earthwork heritage monument that is unprotected or vulnerable to damage, both environmental and anthropogenic.

7.2.1 Current Use

The aerial imagery gathered does not solely have to be used in the methodology set out in this PhD. The aerial imagery at Pilsbury Castle showed badger set damage present on the slopes closest to the River Dove, as explained in Chapter 3. This type of damage would be something of interest in the monitoring of site health as at the time of data collection in February 2020, the badger set damage had not been identified by PDNPA personnel. The aerial imagery of that section of Pilsbury Castle was provided to allow for investigation into the extent of the damage.

The PDNPA had interest in this work, and it was covered in three pages of the Archaeology and Conservation in Derbyshire and the Peak District (ACiD) magazine, which can be seen in *Appendix J*.

7.2.2 Contribution to Research

This PhD provides a methodology to follow in the hypothetical model reconstruction of earthwork heritage sites in the UK, by using both contemporary data and archaeologists' theorised data for heights and depths in order to create a hypothetical model of what it once may have appeared in history to those who constructed them.

It used software that is not unknown to archaeologists or geographers, and still it would benefit even more from interdisciplinary involvement to enhance and ensure numbers and data are as clear as they could be. Volumetric analysis of earthwork heritage is not new, not for stratigraphic analysis (Reilly, 1991), but Dell'Unto and Landeschi (2022) did suggest there were limits to this type of research. Whilst not an answer to stratigraphic analysis and volume, by using UAVs as the data collection platform, this may provide an insight to volume analysis of earthwork sites where it appears to be of much use, particularly when caring for them. Researchers have been using 3D modelling software on artefacts (de Reu et al., 2014) to active excavations (de Reu et al., 2013), Vilbig *et al.,* (2020) used a UAV in surveying the Cahokia mounds to good effect, and Themistocleous *et al.,* (2015) documented an old church in Cyprus effectively using UAVs and 3D modelling; the intent is to fit in this gap of using UAVs as effective, in use and in cost as Sozzi *et al.,* (2021) defined, platforms for data collection for volumetric analysis and documentation. The latter has been commonplace since the start of aerial imagery as part of archaeology, and the former has been achieved in this PhD, with high resolution imagery produced.

Documentation and monitoring could mean that NGOs can have databases of digital models, high resolution aerial imagery that may be used in their efforts to care for their sites, and beyond to raising awareness in the public sphere. This could also be used by researchers; it has been of some interest to investigations such as Falconer *et al.,* (2020) in understanding the more intangible aspects of a site by using virtual reality headsets and immersing the public in a hypothetical world around Avebury henge, with the addition of sound to flesh it out for those partaking. The hypothetical reconstructions of this PhD could be used part of immersion and intangible heritage research.

The author acknowledges that this methodology is very dependent on landscape and vegetation presence, and prior research is required to utilise theorised heights and depths of an earthwork heritage site. As has been offered by Unger *et al.,* (2020) by the contemporary nature, these sites, and other heritage locations, are usually incomplete, and any type of virtual or digital model is a hypothesis that was created using both researchers' estimations on height and depth, and by what data remains at a site. This site may once have reached this remnant height or depth in it's past, and if it did, here is how it may have appeared in its space.

7.2.3 Potential Directions

The fourth objective, as explained prior, was about discussing where else these digital models could be used for awareness, academic research and accessibility. Contributions and suggestions of where this PhD fits within research is one part, but there are other directions that it could be of use beyond academic research. As discussed in Chapter 6 more widely, is the accessibility for those who cannot reach heritage because of transport, medical, or sociographic issues and concerns.

A key objective of this research was to discuss how the visualisations and models can aid in the spread of awareness of heritage and the dangers to them via platforms that are commonly used by the public. Considering the damage that can be wrought on these types of sites, whether by wear and tear over time that occurs without human action, or from increased tourism, agricultural activity, urban encroachment or lack of protection from NGOs, informing and increasing awareness is imperative as part of the monitoring of earthwork heritage.

As mentioned in Chapter 6, this investigation cannot cover the scope and detail deserved of combating racial inequality in visitors to greenspaces, nor that of disabled individuals or other sociographic issues, but digital heritage could be either useful stepping stones in presenting information for those who felt unwelcome, typically BAME individuals and families (CPRE, 2021) or for those who cannot physically access heritage due to physical landscape barriers or illness; disabled people are an often forgotten part of tourism (Guttentag, 2010), and should be able to access heritage as much as abled people theoretically can, barring other limitations. There is no panacea for all disabilities, but there is technology that can aid in that accessibility, like 3D printed models in museum exhibits as part of sensory museums, and not just to have a larger model in a museum exhibition, which is also a potential.

8 References

'Bodies in the Shed (Glendon)', (2006), *Time Team*, Series/Season 13, Episode 1, Directed by Emily Boulting and Michael Douglas (series director), Channel 4, 22nd January 2006

Aarts, B., (2007), 'Motte-and-bailey castles of Europe. Some aspects concerning their origin and evolution', *Virtus. Jaarboek voor adelsgeschiedenis*, **14**, p. 37-56

Ackermann, H., (2014), 'Factorization', *In:* Ikeuchi, K., (ed.), *Computer Vision*, Springer, Boston

Agapiou, A., and Lysandrou, V., (2015), 'Remote sensing archaeology: tracking and mapping evolution in European scientific literature from 1999 to 2015', *Journal of Archaeological Science: Reports*, **4**, p. 192-200

AgiSoft LLC, (2019), 'About Metashape', ONLINE, https://www.agisoft.com/, accessed 30th April 2019

Aicardi, I., Chiabrando, F., Lingua, A., and Noardo, F., (2018), 'Recent trends in cultural heritage 3D survey: the photogrammetric computer vision approach', *Journal of Cultural Heritage*, **32**, p. 257-266

Akturk, E., and Altunel, A. O., (2019), 'Accuracy assessment of a low-cost UAV derived digital elevation model (DEM) in a highly broken and vegetated terrain', *Measurement*, **136**, p. 382-386

Alboul, L., Beer M., and Nisiotis, L., (2019), 'Robotics and virtual reality gaming for cultural heritage preservation', *In:* Dorban, F., (*ed.*), *Resilience and sustainability of cities in hazardous environments*, GVES, p. 335-345

Alcock, L., (1950), 'The henge monument of the Bull Ring, Dove Holes, Derbyshire', *In*: Proceedings of the Prehistoric Society, **16**, Cambridge University Press, p. 81-86

Alexakis, D., Sarris, A., Astaras, T., and Albanakis, K., (2011), 'Intergrated GIS, remote sensing and geomorphologic approaches for the reconstruction of the landscape habitation of Thessaly during the Neolithic period', *Journal of Archaeological Science*, **38**(1), p. 89-100

Alidoost, F., and Arefi, H., (2017), 'Comparison of UAS-based photogrammetry software for 3D point cloud generation: a survey over a historical site', *ISPRS Annals of Photogrammetry, Remote Sensing and Spatial Information Sciences*, **4**, p. 55-61

Allen, K. M. S., Green, S. W., and Zubrow, E. B. W., (eds.), (1990), *Interpreting Space: GIS and Archaeology*, Taylor & Francis, London

Altaweel, M., (2005), 'The use of ASTER satellite imagery in archaeological contexts', *Archaeological Prospection*, **12**(3), p. 151-166

Altmaier, A., and Kany, C., (2002), 'Digital surface model generation from CORONA satellite images', *ISPRS Journal of Photogrammetry and Remote Sensing*, **56**(4), p. 221-235

Alvarez, J., and Michaud, L., (2008), 'Serious Games: advergaming, edugaming, training and more', IDATE

Anderson, E. F., McLoughlin, L., Liarokapis, F., Peters, C., Petridis, P., and de Freitas, S., (2009), 'Serious Games in Cultural Heritage', *In:* Ashley, M., and Liarokapis, F., (eds.) *The 10th International Symposium on Virtual Reality, Archaeology and Cultural Heritage VAST*, p. 29-48

Archaeological Data Service, (2018), 'National Mapping Programme', ONLINE, http://archaeologydataservice.ac.uk/archives/view/NMP/, accessed 7th November 2018

Arnab, S., Petridis, P., Dunwell, I., and de Freitas, S., (2011), 'Enhancing learning in distributed virtual worlds through touch: a browser-based architecture for haptic interaction', *In:* Ma, M., Okionomou, A., and Jain, L. C., (eds.), *Serious Games and Edutainment Applications*, p. 149–167, Springer

Arrunnapaporn, A. B., (2009), 'Interpretation of intangible: Atrocity heritage of 'Death Railway' of the River Kwai', *In*: Lira, S., Arnoeda, R., Pinheiro, C., Pinheiro, J., and Oliveira, F., (eds.), *Sharing Cultures 2009, International Conference on Intangible Heritage*, Green Lines Institute, Barcelos, Portugal, p. 149–156

Assets', Swindon, Historic England, ONLINE, https://historicengland.org.uk/images-books/publications/iha-prehistoric-barrows-burial-mounds/heag217-prehistoric-barrows-burial-mounds/, accessed 9th August 2022

Balletti, C., Ballarin, M., and Guerra, F., (2017), '3D printing: State of the art and future perspectives', *Journal of Cultural Heritage*, **26**, p. 172-182

Barnatt, J., (1989a), 'Gib Hill 8.7', *The Peak District Barrow Survey*, unpublished report for the Derbyshire Archaeological Advisory Committee, Peak Park Joint Planning Board archaeological archive

Barnatt, J., (1989b), *The Peak District Barrow Survey, (volume 2)*, unpublished report for the Peak Park Joint Planning Board

Barnatt, J., (1990), *The Henges, Stone Circles and Ringcairns of the Peak District*, Sheffield Archaeological Monographs 1, University of Sheffield Department of Archaeology and Prehistory, Sheffield

Barnatt, J., (1991a), *Pilsbury Farm, Hartington Town Quarter, Derbyshire Archaeological Survey 1991*, Archaeological Interpretation, Unpublished report for Peak Park Joint Planning Board

Barnatt, J., (1991b), *Upper Oldhams Farm, Middleton by Youlgreave, Derbyshire Archaeological Survey 1991*, Archaeological Interpretation and Recommendations on Presentation, Unpublished report for Peak Park Joint Planning Board

Barnatt, J, (1993), *Upper Oldhams Farm – Stanton Estate Land, Middleton by Youlgreave, Derbyshire*, Archaeological Survey 1993, Unpublished report for Peak Park Joint Planning Board

Barnatt, J., (2000), 'To each their own: later prehistoric farming communities and their monuments in the Peak', *Derbyshire Archaeological Journal,* **120**, p. 1-86

Barnatt, J., (2019), *Reading the Peak District Landscape*, Historic England, Swindon

Barnatt, J., and Collis, J., (1996), *Barrows in the Peak District: Recent Research*, J. R. Collis Publications, Sheffield

Barnatt, J., and Myers, A., (1988), 'Excavations at the Bull Ring Henge, Dove Holes, Derbyshire, 1984-85', *Derbyshire Archaeological Journal*, **108**, p. 5-20

Barnatt, J., and Penny, R., (2004), 'The Prospects for the Peak District's Lead Mining Heritage', Peak District National Park

Barnatt, J., and Smith, K., (2004), *The Peak District*, (2nd ed.), Windgather Press, Macclesfield

Bassier, M., Vincke, S., de Lima Hernandez, R., and Vergauwen, M., (2018), 'An overview of Innovative Heritage Deliverables Based on Remote Sensing Techniques', *Remote Sensing*, **10**(10), 1607

Bateman, T., (1848), *Vestiges of the Antiquities of Derbyshire*, London.

Bateman, T., (1861), *Ten Years Digging in Celtic and Saxon Grave-Hills in the Counties of Derby, Stafford, and York*, London and Derby

BBC, 2020, 'Minecraft: Lockdown lesson recreates ancient island tomb', ONLINE, https://www.bbc.co.uk/news/uk-wales-53239650, accessed 14th October 2020

Bender, B., (1993), 'Introduction: Landscape – meaning and action', *In:* Bender, B., (ed.), *Landscape: politics and perspectives*, Providence/Oxford, Berg, p. 1-18

Bennett, R., Welham, K., Hill, R. A., and Ford, A., (2012), 'A comparison of visualisation techniques for models created from Airborne Laser Scanned Data', *Archaeological Prospection*, **19**, p. 41-48

Bentkowska-Kafel, A., and Macdonald L., (2018), *Digital techniques for documenting and preserving cultural heritage*, Collection Development, Arc Humanities Press, Leeds

Beresford, M., (2010), *Elmton Castle Research Project: Interim Report*

Bevan, B., (2005), 'Peaks Romana: the Peak District Romano-British rural upland settlement survey', *Derbyshire Archaeological Journal*, **125**, p. 26-58

Bewley, B., (2001), ‘Understanding England’s historic landscapes: an aerial perspective’, *Landscapes*, **2**(1), p. 74-84

Bewley, R. H., (2003), ‘Aerial survey for archaeology’, *Photogrammetric Record*, **18**(104), p. 273-292

Bhardwaj, A., Sam, L., Akanksha, Martin-Torres, F. J., and Kumar, R., (2016), ‘UAVs as remote sensing platform in glaciology: Present applications and future prospects’, *Remote Sensing of Environment*, **175**, p. 196-204

Bollandsås, O. M., Risbøl, O., Ene, L. T., Nesbakken, A., Gobakken, T., and Næsset, E., (2012), ‘Using airborne small-footprint laser scanner data for detection of cultural remains in forests: an experimental study of the effects of pulse density and DTM smoothing’, *Journal of Archaeological Science*, **39**, p. 2733-2743

Booth, N., Cummings, J., Norton, J., and Whibberley, T., (1996), ‘The Arbor Low Visitor 1996. Report of visitor survey conducted at Arbor Low stone circle and Gib Hill barrow in the parish of Middleton and Smerrill in Derbyshire’, Unpublished report towards GNVQ in Leisure and Tourism, Buxton Community School, Buxton

Born, J., and Valli, I., (2012), ‘UAVs compared to Traditional Surveying’, *GeoInformatics*, **15**(2), p. 14-15

Bourdieu, P., (1977), *Outline of theory of practice*, Cambridge University Press, Cambridge

Bradley, R., (2011), *Stages and Screens: An investigation of four henge monuments in northern and north-eastern Scotland*, Societies of Antiquaries of Scotland, Edinburgh

Bradley, R., (2020), ‘Time Signatures: the temporality of monuments in Early and Middle Neolithic Britain’, *Proceedings of the Prehistoric Society*, **86**, p. 1-11

Bramwell, D., (1959), ‘The Excavation of Dowel Cave, Earl Sterndale 1958-9’, *Derbyshire Archaeological Journal,* **79**, p. 97-109

Bramwell, D., (1971), ‘Excavations at Foxhole Cave, High Wheeldon, 1961-1970’, *Derbyshire Archaeological Journal*, **91**, p. 1-19

British Geological Society, (2020), ‘Bowland Shale Formation’, ONLINE, https://www.bgs.ac.uk/lexicon/lexicon.cfm?pub=BSG, accessed 19th February 2020

Bruno, F., Bruno, S., De Sensi, G., Luchi, M.L., Mancuso, S. and Muzzupappa, M., (2010), ‘From 3D reconstruction to virtual reality: A complete methodology for digital archaeological exhibition’, *Journal of Cultural Heritage*, **11**(1), p. 42-49

Brutto, M. L., and Meli, P., (2012), ‘Computer Vision Tools for 3D Modelling in Archaeology’, *International Journal of Heritage in the Digital Era*, **1**, p. 1-6

Brutto, M. L., Borruso, A., and D'Argenio, A., (2012), 'UAV systems for photogrammetric data acquisition of archaeological sites', *International Journal of Heritage in the Digital Era*, **1**, p. 7-14

Burl, A., (1979), *Rings of Stone: the prehistoric stone circles of Britain and Ireland*, Weidenfeld & Nicolson, London, Lincoln

Burl, A., (2000), *A guide to the Stone Circles of Britain, Ireland and Brittany*, (*Revised Ed.*), Yale University Press, USA

Burns, J. H. R., and Delparte, D., (2017), 'Comparison of Commercial Structure-From-Motion Photogrammetry Software used for Underwater Three-Dimensional Modeling of Coral Reef Environments', *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences,* **42**, p. 127-131

Burrough, P. A., and McDonnell, R., (1998), 'Principles of geographical information systems', Oxford

Cachia, A., (2013), 'Talking blind: disability, access, and the discursive turn', *Disability Studies Quarterly*, **33**(3), p. 1-20

Calin, M., Damian, G., Popescu, T., Manea, R., Erghelegiu, B., & Salagean, T. (2015), '3D modeling for digital preservation of Romanian heritage monuments', *Agriculture and Agricultural Science Procedia,* **6**, p. 421-428

Camden, W., (1586), *Britannia, sive florentissimorum Regnorum Angliae, Scotiae, Hiberniae et Insularum adiecentium, ex intima antiquitate chorographica descriptio* [Britain, or the most flourishing of the kingdoms of England, Scotland, and Ireland, and of the Isles adiecentes, a description of the intimate sense of antiquity is of ancient euisq], London

Campana, S., (2017), 'Drones in archaeology. State-of-the-art and future perspectives', Archaeological Prospection, **24**(4), p. 275-296

Campana, S., (2020), 'Drone-Based Imaging in Archaeology: Current Applications and Future Prospects', *In:* Green, D. R., Gregory, B. J., and Karachok, A. R., (eds.), *Unmanned Aerial Remote Sensing: UAS for Environmental Applications*, CRC Press, Boca Raton, p. 217-239

Carr, J. C., and Slyder, J.B., (2018), 'Individual tree segmentation from a leaf-off photogrammetric point cloud', *International Journal of Remote Sensing*, **39**(15-16), p. 5195-5210

Carvajal-Ramirez, F., Navarro-Ortega, A. D., Aguera-Vega, F., Martinez-Carricondo, P., and Mancini, F., (2019), 'Virtual reconstruction of damaged archaeological sites based on Unmanned Aerial Vehicle Photogrammetry and 3D modelling. Study case of a southeastern Iberia production area in the Bronze Age', *Measurement*, **136**, p. 225-236

Casbeer, D. W., Kingston, D. B., Beard, R. W., and McLain, T. W., (2006), 'Cooperative forest fire surveillance using a team of small unmanned air vehicles', *International Journal of Systems Science*, **37**(6), p. 351-360

Cerato, I., & Pescarin, S., (2013), 'Reconstructing past landscapes for virtual museums'. *In:* Corsi, C., Slapšak, B., Vermeulen, F. (eds), *Good Practice in Archaeological Diagnostics*, Springer, Cham, p. 285-296

Ceraudo, G., (2013), 'Aerial Photography in Archaeology', *In*: Corsi, C., Slapšak, B., and Vermeulen, F., (eds.), *Good Practice in Archaeological Diagnostics,* Springer, Cham, p. 11-30

Ch'ng, E., Cai, Y., and Thwaites, H., (2018), 'Special issue on VR for culture and heritage: The experience of cultural heritage with virtual reality: guest editors' introduction,' *Presence: Teleoperators and Virtual Environments*, **26**(4), p. iii-iv

Challis, K., Carey, C., Kincey, M., and Howard, A. J., (2011a), 'Airborne Lidar Intensity and Geoarchaeological Prospection in River Valley Floors', *Archaeological Prospection*, **18**, p. 1-13

Challis, K., Forlin, P., and Kincey, M., (2011b), 'A Generic Toolkit for the Visualization of Archaeological Features on Airborne LiDAR Elevation Data', *Archaeological Prospection*, **18**(4), p. 279-289

Challis, K., Kokalj, Z., Kincey, M., Moscrop, D., and Howard, A. J., (2008), 'Airborne laser and historic environment records', *Antiquity*, **82**, p. 1055-1064

Champion, E., (2012), *Game Mods: Design, Theory and Criticism,* Entertainment Technology Centre Press, Pittsburgh

Champion, E., (2017), 'Bringing your A-game to digital archaeology: issues with serious games and virtual heritage and what we can do about it', *In:* SAA Archaeological Record: Forum on Digital Games and Archaeology, **17**(2), p. 24-27

Champion, E., and Rahaman, H. (2020), '3D digital heritage models as sustainable scholarly resources', *Sustainability,* **11**(8), p. 1-8

Champion, E., and Rahaman, H., (2019), 'To 3D or not 3D: choosing a photogrammetry workflow for cultural heritage groups', *Heritage*, **2**(3), p. 1835-1851

Chase, A. F., Chase, D. Z., Weishampel, J. F., Drake, J. B., Shrestha, R. L., Slatton, K. C., Awe, J. J.., and Carter, W. E., (2011), 'Airborne LiDAR, archaeology, and the ancient Maya landscape at Caracol, Belize', *Journal of Archaeological Science*, **38**(2), p. 387-398

Chen, F., Lasaponara, R., and Masini, N., (2017), 'An overview of satellite synthetic aperture radar remote sensing in archaeology: From site detection to monitoring', *Journal of Cultural Heritage*, **23**, p. 5-11

Childs, C., (2004), 'Interpolation surfaces in ArcGIS spatial analyst', *ArcUser*, **3235**, p. 569

Chorley, R. J, and Haggett, P., (1967), *Models in Geography*, Methuen, London

Ciminale, M., Gallo, D., Lasaponara, R., and Masini, N., (2009), 'A multiscale approach for reconstructing archaeological landscapes: applications in Northern Apulia (Italy)', *Archaeological Prospection*, **16**, p. 143-153

Civil Aviation Authority (CAA), (2020a), 'CAP2006: Drone Rules: Flying in the Countryside', ONLINE, https://publicapps.caa.co.uk/docs/33/CAP2006_EU_Drone_Rules_Factsheet_V7%204.pdf, accessed 8th June 2022

Civil Aviation Authority (CAA), (2020b), 'CAP2007: Drone Rules: Flying in Towns and Cities', ONLINE, https://publicapps.caa.co.uk/docs/33/CAP2007_EU_Drone_Rules_Factsheet_V7%205.pdf, accessed 8th June 2022

Clapuyt, F., Vanacker, V., and Van Oost, K., (2016), 'Reproducibility of UAV-based earth topography reconstructions based on Structure-from-Motion algorithms', *Geomorphology*, **260**, p. 4-15

Clarke, D. L., (1972), 'Models and Paradigms in contemporary archaeology', *In:* Clarke, D. L., (ed.), *Models in Archaeology*, Methuen, London

Clarke, K. C., (1986), 'Advances in Geographic Information Systems', *Computers, Environment, and Urban Systems*, **10**(3-4), p. 175-184

Coates, B. E., (1965), 'The Origin and Distribution of Markets and Fairs in Medieval Derbyshire', *Derbyshire Archaeological Journal*, **85**, p. 92-111

Cohen, N., (2009), '*Microsoft Encarta Dies After Long Battle With Wikipedia*', *New York* Times, 30th March 2009, ONLINE, https://bits.blogs.nytimes.com/2009/03/30/microsoft-encarta-dies-after-long-battle-with-wikipedia/, accessed 21st March 2019

Colomina, I., and Molina, P., (2014), 'Unmanned aerial systems for photogrammetry and remote sensing: A review', *ISPRS Journal of Photogrammetry and Remote Sensing*, **92**, p. 79-97

Consolvo, S., Klasnja, P., McDonald, D.W., Avrahami, D., Froehlich, J., LeGrand, L., Libby, R., Mosher, K. and Landay, J.A., (2008), 'Flowers or a robot army? Encouraging awareness & activity with personal, mobile displays', *Proceedings of the 10th international conference on Ubiquitous computing,* p. 54-63

Cook Inlet Tribal Council, (2017), 'Storytelling for the Next Generation: How a non-profit in Alaska harnessed the power of video games to share and celebrate cultures', *In:* Mol, A. A. A., Ariese-Vandemeulebroucke, C. E., Boom, K. H. J., and Politopoulos, A., *The Interactive Past: Archaeology, Heritage and Video Games*, Sidestone Press, Leiden, p. 21-33

Cook, Lt. K. L. B., (2007), 'The silent force multiplier: The history and role of UAVs in warfare', *In:* IEEE (Institute of Electrical and Electronics Engineers), (eds.), *Proceedings of the 2007 IEEE Aerospace Conference*, p. 1-7

Coombs, D., (1976), 'Excavations at Mam Tor, Derbyshire, 1965-1969', *In:* Harding, D. W., (ed.), *Hillforts: Later prehistoric earthworks in Britain and Ireland*, Academic Press, London

Council for the Preservation of Rural England (CPRE), (2021), 'Access to nature in the English Countryside', ONLINE, https://www.cpre.org.uk/wp-content/uploads/2021/08/August-2021_Access-to-nature-in-the-English-countryside_research-overview.pdf, accessed 21st August 2022

Council of Europe, (2000), ONLINE, 'European Landscape Convention', Council of Europe Cultural Heritage, Landscape and Spatial Planning Division, France, https://rm.coe.int/CoERMPublicCommonSearchServices/DisplayDCTMContent?documentId=09000016802f80c6, accessed 8th October 2019

Council of Europe, (2023), 'United Kingdom – England', ONLINE, https://www.coe.int/en/web/herein-system/united-kingdom-england, accessed 16th Februrary 2023

Crawford, O. G. S., (1954), 'A century of Air-photography', *Antiquity*, **28**(112), p. 206-210

Crawford, O. G. S., and Keiller, A., (1928), *Wessex from the Air*, Clarendon Press, Oxford

Crow, P., Benham, S., Devereux, B. J., and Amable, G. S., (2007), 'Woodland vegetation and its implications for archaeological survey using LiDAR', *Forestry: An International Journal of Forest Research*, **80**(3), p. 241-252

Cuba, L., and D. M. Hummon., (1993), 'A place to call home: Identification with dwelling, community, and region', *Sociology Quarterly*, **34**, p. 111–131

Dalglish, C., (2012), 'Archaeology and landscape ethics', *World Archaeology*, **44**(3), p. 327-341

Daniel, T.C., (1990), 'Measuring the quality of the natural environment: a psychophysical approach', *American Psychologist*, **45**, p .633–637

Darvill, T., (2008), 'Earthworks', *In:* The Concise Oxford Dictionary of Archaeology, Oxford University Press, ONLINE, https://www.oxfordreference.com/view/10.1093/acref/9780199534043.001.0001/acref-9780199534043-e-1299, accessed 26th July 2022

Dashora, A., Lohani, B., and Malik, J. N., (2007), 'A repository of earth resource information – CORONA satellite programme', *Current Science*, **92**(7), p. 926-932

Davenport, M. A., and D. H. Anderson, (2005), ‘Getting from sense of place to place-based management: An interpretive investigation of place meanings and perceptions of landscape change’, *Society Nat. Resources*, **18**, p. 625–641

de Freitas, S., and Liarokapis, F., (2011), ‘Serious games: a new paradigm for education?’ *In:* Ma, M., Okionomou, A., and Jain, L. C., (eds.), *Serious Games and Edutainment Applications*, Springer, p. 9–23

De Groot, W. T., and van den Born, R. J. G., (2003), ‘Visions of nature and Landscape type preferences; an exploration in the Netherlands’, *Landscape and Urban Planning*, **63**, p. 127-138

De Reu, J., De Smedt, P., Herremans, D., van Meirvenne, M., Laloo, P., and de Clercq, W., (2014), ‘On introducing an image-based 3D reconstruction method in archaeological excavation practice’, *Journal of Archaeological Science*, **41**, p. 251-262

De Reu, J., Plets, G., Verhoeven, G., De Smedt, P., Bats, M., Cherrette, B., De Maeyer, W., Deconynck, J., Herremans, D., Laloo, P., Van Merivenne, M., and De Clercq, W., (2013), ‘Towards a three-dimensional cost-effective registration of the archaeological heritage’, *Journal of Archaeological Science*, **40**, p. 1108-1121

Defoe, D., (1727), *A Tour Thro’ the Whole Island of Great Britain, Volume 3*, London

Dell’Unto N., and Landeschi, G., (2022), *Archaeological 3D GIS*, Routledge, Abingdon

Denham, T., (2017), ‘Landscape Archaeology’, *In:* Gilbert, A. S., (ed.), *Encyclopaedia of Geoarchaeology*, Encyclopaedia of Earth Sciences Series, Springer, Dordrecht, p. 464-469

Dennison, S., (2022), ‘Extending the right to roam: The Countryside Code, Covenant and Christianity’, *The JRI (John Ray Initiative) Briefing Papers*, **46**, p. 1-12

Devereux, B. J., Amable, G. S., and Crow, P., (2008), ‘Visualisation of LiDAR terrain models for archaeological feature detection’, *Antiquity*, **82**, p. 470-479

DJI, (2019), ‘Phantom 4’, ONLINE, https://www.dji.com/uk/phantom-4, accessed 4th June 2019

DJI, (2023), ‘Phantom 4 Series Intelligent Flight Battery’, ONLINE, https://m.dji.com/uk/product/phantom-4-pro-intelligent-battery-high-capacity, accessed 7th March 2023

Doyle, J., Viktor, H., & Paquet, E. (2009), ‘Long-term digital preservation: preserving authenticity and usability of 3-D data’, *International Journal on Digital Libraries,* **10**(1), p. 33-47

Drayton, M., (1622), *The second part, or a continuance of Poly-Olbion from the eighteenth song*, Augustine Mathewes, London

Drone Safe, (2018), ‘Drone code’, ONLINE, https://dronesafe.uk/drone-code/, accessed 28th November 2018

Drones-Made-Easy, (2019), ‘Map Pilot for DJI’, ONLINE, https://www.dronesmadeeasy.com/Articles.asp?ID=254, accessed 18th June 2019

Dyer, J., (2003), *Hillforts of England and Wales*, (2nd, revised ed.), Shire Publications, Oxford

Edensor, T., (2017), ‘Rethinking the landscape of the Peak District’, *Landscape Research*, **42**(6), p. 595-600

Edina Digimap, (2018), Edina Digimap Ordnance Survey Service, 1:50 000 Scale Colour Raster [TIFF geospatial data], ONLINE, https://digimap.edina.ac.uk, accessed 30th October 2018

Edmonds, M., and Seaborne, T., (2001), *Prehistory in the Peak*, Tempus, Stroud

Edwards, J., (2017), ‘The Land to Forget: tourism, caving and writing in the Derbyshire White Peak’, *Landscape Research*, **42**(6), p. 634-649

Eisenbeiss, H., and Sauerbier, M., (2011), ‘Investigation of UAV systems and flight modes for photogrammetric applications’, *The Photogrammetric Record*, **26**(136), p. 400-421

Eisenbeiss, H., and Zhang, L., (2006), ‘Comparison of DSMs generated from mini UAV imagery and terrestrial laserscanner in a cultural heritage application’, *The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, **36**(5), p. 90-96

English Heritage, (2018a), ‘Description of Avebury Henge and Stone Circles’, ONLINE, https://www.english-heritage.org.uk/visit/places/avebury/history/description/, accessed 6th November 2018

English Heritage, (2018b), ‘History of Avebury Henge and Stone Circles’, ONLINE, https://www.english-heritage.org.uk/visit/places/avebury/history/, accessed 14th November 2018

Erasmi, S., Rosenbaur, R., Buchbach, R., Busche, T., and Rutishauser, S., (2014), ‘Evaluating the Quality and Accuracy of TanDEM-X Digital Elevation Models at Archaeological Sites in the Cilician Plain, Turkey’, *Remote Sensing*, **6**(10), p. 9475-9493

Erenoglu, R. C., Akcay, O., and Erenoglu, O., (2017), ‘An UAS-assisted multi-sensor approach for 3D modelling and reconstruction of cultural heritage site’, *Journal of Cultural Heritage*, **26**, p. 79-90

ESA (European Space Agency), (2018), ‘Radar Course 2: Synthetic Aperture Radar (SAR)’, ONLINE, https://earth.esa.int/web/guest/missions/esa-operational-eo-missions/ers/instruments/sar/applications/radar-courses/content-2/-/asset_publisher/qIBc6NYRXfnG/content/radar-course-2-synthetic-aperture-radar, accessed 21st November 2018

Esri, (2004), ‘ArcGIS 9. What is ArcGIS?’, ONLINE, http://downloads.esri.com/support/documentation/ao_/698What_is_ArcGis.pdf, accessed 11th June 2019

Esri, (2017), ‘Why You Should Move to ArcGIS Pro’, ONLINE, https://www.esri.com/about/newsroom/arcuser/why-you-should-move-to-arcgis-pro/, accessed 17th August 2022

Esri, (2018a), ‘About ArcGIS: The mapping and analytics platform’, ONLINE, https://www.esri.com/en-us/arcgis/about-arcgis/overview, accessed 13th November 2018

Esri, (2018b), ‘Hillshade function’, ONLINE, http://desktop.arcgis.com/en/arcmap/latest/manage-data/raster-and-images/hillshade-function.htm, accessed 13th November 2018

Esri, (2018c), ‘Slope function’, ONLINE, http://desktop.arcgis.com/en/arcmap/latest/manage-data/raster-and-images/slope-function.htm, accessed 13th November 2018

Esri, (2018d), ‘Aspect function’, ONLINE, http://desktop.arcgis.com/en/arcmap/latest/manage-data/raster-and-images/aspect-function.htm, accessed 13th November 2018

Esri, (2019a), ‘ArcGIS Desktop’, ONLINE, http://desktop.arcgis.com/en/, accessed 29th April 2019

Esri, (2019b), ‘Clip’, ONLINE, https://pro.arcgis.com/en/pro-app/tool-reference/analysis/clip.htm, accessed 2nd May 2019

Esri, (2019b), ‘How HillShade works’, ONLINE, https://pro.arcgis.com/en/pro-app/tool-reference/3d-analyst/how-hillshade-works.htm, accessed 29th April 2019

Esri, (2019c), ‘How Cut Fill works’, ONLINE, http://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-analyst-toolbox/how-cut-fill-works.htm, accessed 21st May 2019

Esri, (2019d), ‘Cut Fill’, ONLINE, http://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-analyst-toolbox/cut-fill.htm, accessed 22nd May 2019

Esri, (2021), ‘How Raster Calculation Works’, ONLINE, https://pro.arcgis.com/en/pro-app/latest/tool-reference/spatial-analyst/how-raster-calculator-works.htm, accessed 14th October 2021

Esri, (2022), ‘What is GIS?’, ONLINE, https://www.esri.com/en-us/what-is-gis/overview, accessed 29th August 2022

Everaerts, J., (2008), ‘The use of unmanned aerial vehicles (UAVs) for remote sensing and mapping’, *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Services*, **37**, p. 1187-1192

Fairclough, G. & Rippon, S., (2002), ‘Conclusion: archaeological management of Europe’s cultural landscape’, *In:* G. Fairclough & S. Rippon (eds.), *Europe’s Cultural Landscape: Archaeologists and the Management of Change*, **2**, p. 201 – 206, Short Run Press, Exeter

Fairclough, G., (1999), ‘Philosophy and Interpretation’, *In:* Fairclough, G., Lambrick, G., and McNab, A., (eds.) *Yesterday’s World, Tomorrow’s Landscape. The English Heritage Landscape Project, 1992-94*, p. 9-17. English Heritage, London

Falconer, L., Burden, D., Cleal, R., Hoyte, R., Phelps, P., Slawson, N., Snashall, N., and Welham, K., (2020), ‘Virtual Avebury: Exploring sense of place in a virtual archaeology simulation’, *Virtual Archaeology Review*, **11**(23), p. 50-62

Faltýnová, M., and Nový, P., (2014), ‘Airborne laser scanning and image processing techniques for archaeological prospection’, *The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, **40** (5), p. 231-235

Fang, J., Zhang, Y., Zhang, Y., Guo, H., and Sun, Z., (2022), ‘High-definition survey of architectural heritage fusing multisensors – The case of Beamless Hall at Linggu Temple in Nanjing, China’, *Sensors*, **22**(9), Article No. 3369

Fazio, L., and Brutto, M. L., (2020), ‘3D Survey for the Archaeological Study and Virtual Reconstruction of the “Sanctuary of Isis” in the Ancient Lilybaeum (Italy)’, *Virtual Archaeology Review*, **11**(22), p. 1-14

Federman, A., Shrestha, S., Quintero, M. S., Mezzino, D., Gregg, J., Kretz, S., and Ouimet, C., (2018), ‘Unmanned Aerial Vehicles (UAV) Photogrammetry in the Conservation of Historic Places: Carleton Immersive Media Studio Case Studies’, *Drones*, **2**(2), Article No. 18

Fernandez-Hernandez, J., Gonzalez-Aguilera, D., Rodriguez-Gonzalvez, P., and Mancera-Taboada, J., (2015), ‘Image-based modelling from unmanned aerial vehicle (UAV) photogrammetry: an effective, low-cost tool for archaeological applications’, *Archaeometry*, **57**(1), p. 128-145

Fonstad, M. A., Dietrich, J. T., Courville, B. C., Jensen, J. L., Carbonneau, P. E., (2013), ‘Topographic structure from motion: a new development in photogrammetric measurement’, *Earth Surface Processes and Landforms*, **38**, p. 421-430

Ford, T. D., (1994), ‘Blue John fluorspar’, *Geology Today*, **10**(5), p. 186-190

Ford, T. D., (2002), ‘Dolomitization of the Carboniferous Limestone of the Peak District: a review’, *Mercian Geologist*, **15**(3), p. 163-170

Forman, R., and Godron, M., (1986), *Landscape Ecology*, John Wiley & Sons, New York

Forte, M., (2019), 'Virtual Reality Modelling', *The Encyclopedia of Archaeological Sciences*, p. 1-4

Fouberg, E. H., Murphy, A. B., and de Blij, H. J., (2020), Human Geography: People, Place and Culture, (12th ed.), Wiley, Hoboken, N.J

Fowler, M. J. F., (2002), 'Satellite remote sensing and archaeology: a comparative study of satellite imagery of the environs of Figsbury Ring, Wiltshire', *Archaeological Prospection*, **9**, p. 55-69

Fraser, B. T., and Congalton, R. G., (2018), 'Issues in Unmanned Aerial Systems (UAS) data collection of complex forest environments', *Remote Sensing*, **10**, Article No. 908

Fry, G. L. A., Skar, B., Jerpasen, G., Bakkestuen, V., and Erikstad, L., (2004), 'Locating archaeological sites in the landscape: a hierarchial approach based on landscape indicators', *Landscape and Urban Planning*, **67**, p. 97-107

Fry, G., Tveit, M. S., Ode, A., & Velarde, M. D. (2009), 'The ecology of visual landscapes: Exploring the conceptual common ground of visual and ecological landscape indicators', *Ecological Indicators*, **9**(5), p. 933–947

Furukawa, Y., and Hernandez, C., (2015), 'Multi-View Stereo: A tutorial', *Foundations and Trends ® in Computer Graphics and Vision*, **9**(1-2), p. 1-148

Fussell, A., (1982), 'Terrestrial photogrammetry in archaeology', *World Archaeology*, **14**(2), p. 157-172

Fyfe, R. M., and Woodbridge, J., (2012), 'Differences in time and space in vegetation patterning: analysis of pollen data from Dartmoor, UK', *Landscape Ecology*, **27**, p. 745-760

Gaffney, V., and van Leusen, M., (1995), 'Postscript – GIS, environmental determinism and archaeology: a parallel text', *In:* Lock, G., and Stancic, Z., (eds.), *Archaeology and geographical information systems: a European perspective*, Taylor & Francis, London, p. 366-382

Gaffney, V., Stancic, Z., and Watson, H., (1996), 'Moving from catchments to cognition: tentative steps toward a larger archaeological context for GIS', *In:* Aldenderfer, M., and Maschner, H. D. G., (eds.), *Anthropology, Space, and Geographic Information Systems*, Oxford University Press, Oxford, p. 132-154

Galeazzi, F., (2018), '3-D virtual replicas and simulations of the past: 'real' or 'fake' representations?', *Current Anthropology*, **59**(3), p. 268-286

Galeazzi, F., and Di Franco, D. G., (2017), 'Theorising 3D visualisation systems in archaeology: Towards more effective design, evaluations and life cycles', *Internet Archaeology,* **44**, DOI: https://doi.org/10.11141/ia.44.5

Gallagher, S., (2012), ‘What is Phenomenology?’, *In:* Phenomenology, Palgrave MacMillan, London

Gansum, T., Jerpasen, G., and Keller, C., (1997), ‘Arkeologisk landskapsanalyse med visuelle metoder’, Arkeologisk Museum, Stavanger

Garrison, T. G., Houston, S. D., Golden, C., Inomata, T., Nelson, Z., and Munson, J., (2008), ‘Evaluating the use of IKONOS satellite imagery in lowland Maya settlement archaeology’, *Journal of Archaeological Science*, **35**(10), p. 2770-2777

Gaukstad, E., (1993), ‘Nasjonale verdier og vern av kulturmiljoer’, Riksantikvaren, Stockholm

Gaukstad, E., (2000), ‘Jordbrukslandskapets kulturverdier-utfordring in et trverrsektorielt samarbeid’, *Report Nord 2000*, **18**, Nordisk Ministerrad, Copenhagen

Georgiadou, Y., Knippers, R. A., Sides, E. J., and van Westen, C. J., (2001), ‘Data entry and preparation’, *In:* Principles of Geographic Information Systems (2nd ed.,), de By, R. A., (ed.), The International Institute for Aerospace Survey and Earth Sciences (ITC), Enschede

Gibson, J. J., (1971), ‘A preliminary description and classification of affordances’, Unpublished manuscript, *In:* Reed, E., and Jones, R., (eds.), (1982), *Reasons for realism*, Hillsdale, NJ: Lawrence Erlbaum Associates, Inc., p. 403-406

Gibson, J. J., (1986), *The ecological approach to visual perception*, Erlbaum, Hillsdale, London

Gillings, M., (2012), ‘Landscape Phenomenology, GIS, and the Role of Affordance’, *Journal of Archaeological Method and Theory*, **19**(4), p. 601-611

Gillings, M., and Goodrick, G. T., (1996), ‘Sensuous and Reflexive GIS: Exploring Visualisation and VRML’, *Internet Archaeology*, **1**(1)**,** ONLINE, https://doi.org/10.11141/ia.1.2, accessed 21st March 2019

Goldberg, D., Corcoran, M., and Picard, R. G., (2013), ‘Remotely Piloted Aircraft Systems & Journalism Opportunities and Challenges of Drones in News Gathering’, *Reuters Institute for the Study of Journalism Report,* ONLINE, http://reutersinstitute.politics.ox.ac.uk/sites/default/files/Remotely%20Piloted%20Aircraft%20and%20Journalism_0.pdf

Gomez, C., Hayakawa, Y., and Obanawa, H., (2015), ‘A study of Japanese landscapes using structure from motion derived DSMs and DEMs based on historical aerial photographs: New opportunities for vegetation monitoring and diachronic geomorphology’, *Geomorphology*, **242**, p. 11-20

Gonzalez, J. J. F., and Hernandez, F. R. V., (2019), ‘NDVI identification and survey of a Roman road in the Northern Spanish Province of Alava’, *Remote Sensing*, **11**(6), p. 725

Goodall, B., Pottinger, G., Dixon, T., and Russell, H., (2004), 'Heritage property, tourism and the UK Disability Discrimination Act', *Property Management,* **22**(5), p. 345-357

Goossens, R., De Wulf, A., Bourgeois, J., Gheyle, W., and Willems, T., (2006), 'Satellite imagery and archaeology: the example of CORONA in the Altai Mountains', *Journal of Archaeological Science*, **33**(6), p. 745-755

Goudie, A. S., (1987), 'Geography and Archaeology: the growth of a relationship', *In;* Wagstaff, J. M., (ed.), *Landscape and Culture: Geographical and Archaeological Perspectives*, Basil Blackwell, New York

GRASS GIS, (2019), 'General overview', ONLINE, https://grass.osgeo.org/documentation/general-overview/, accessed 11th June 2019

Gray, H. St. G., (1903), 'On the Excavations at Arbor Low, 1901 - 1902', *Archaeologia*, **58**, p. 461-498

Gray, H. St. G., (1904), 'Arbor Low stone circle: Excavations in 1901 and 1902), *Derbyshire Archaeological Journal*, **26**, p. 41-77

Green, K., (2022),'Virtual reality allows Grantham care home residents to visit place they've always dream of', *Grantham Journal*, 13th August, 2022 ONLINE, https://www.granthamjournal.co.uk/news/virtual-reality-allows-care-home-residents-to-visit-places-t-9268668/?fbclid=IwAR0cTH-aOSQ5-LM-V2zhznZDZyACs0EDJwmbpcnPaqy8dwQEZCZ1DtnAsh4, accessed 22nd August 2022

Green, S. W., (1990a), 'Approaching archaeological space: an introduction to the volume', *In:* Allen, K. M. S., Green, S. W., and Zubrow, E. B. W., (eds.), *Interpreting Space: GIS and archaeology*, Taylor & Francis, London

Green, S. W., (1990b), 'Sorting out settlement in south-eastern Ireland; landscape archaeology and geographic information systems', *In:* Allen, K. M. S., Green, S. W., and Zubrow, E. B. W., (eds.) *Interpreting Space: GIS and archaeology*, Taylor & Francis, London

Green, S., Bevan, A., and Shapland, M., (2014), 'A comparative assessment of structure from motion methods for archaeological research', *Journal of Archaeological Science*, **46**, p. 173-181

Grodach, C., (2002), 'Reconstituting identity and history in post-war Mostar, Bosnia-Herzegovina', *City*, **6**(1), p. 61-82

Guarnieri, A., Pirotti, F., and Vettore, A., (2010), 'Cultural heritage interactive 3D models on the web: An approach using open source and free software', *Journal of Cultural Heritage*, **11**, p. 350-353

Guilbert, G., (1994a), *Arbor Low, Derbyshire. Condition Survey, August 1994*, unpublished report by Trent and Peak Archaeological Trust for English Heritage

Guilbert, G., (1994b), *Gib Hill, Derbyshire. Condition Survey, August 1994*, unpublished report by Trent and Peak Archaeological Trust for English Heritage

Gurjar, S. K., and Tare, V., (2019), 'Estimating long-term LULC changes in an agriculture-dominated basin using CORONA (1970) and LISS IV (2013–14) satellite images: a case study of Ramganga River, India', *Environmental Monitoring and Assessment*, **191**(4), p. 1-15

Guttentag, D. A., (2010), 'Virtual reality: applications and implications for tourism', Tourism Management, 31(5), p. 637-651

Hadzimuhamedovic, A., and Bouchenaki, M., (2018), 'Reconstruction of the Old Bridge in Mostar', *World Heritage*, ONLINE, **86**, p. 20-26, ONLINE, https://en.calameo.com/read/0033299721336e74edda2, accessed 12th December 2018

Hägerhäll, C. (1999), 'The experience of pastoral landscapes', Doctoral Thesis, Department of Landscape Planning, Swedish University of Agricultural Sciences, Alnarp

Haggett, P., (1971), *Locational models in human geography*, Edward Arnold, London

Hails, D., (1997), 'Conducting a Visitor Survey for GNVQ', *Heritage Learning*, 9, p. 12

Hakala, T., Honkavaara, E., Saari, H., Makynen, J., Kaivosoja, J., Pesonen, L., and Polonen, I., (2013), 'Spectral imaging from UAVs under varying illumination conditions', *In:* Grenzdorffer, G., and Bill, R., (eds.), *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences,* Rostock

Halabi, O., Al-Maadeed, S., Puthern, M., Balakrishnan, P. and El-Menshawy, S., (2022), '3D GIS Interactive Visualization of the Archaeological Sites in Qatar for Research and Learning,' *International Journal of Emerging Technologies in Learning (iJET)*, **17**(1), p.160-178

Han, J., Bawary, M. R., and Bruno, A., (2018), 'The Bamiyan Buddhas: Issues of Reconstruction', *World Heritage*, ONLINE, **86**, p. 40-45, ONLINE, https://en.calameo.com/read/0033299721336e74edda2, accessed 12th December 2018

Hansen, M. C., and Loveland, T. R., (2012), 'A review of large area monitoring of land cover change using Landsat data', *Remote Sensing of Environment*, **122**, p. 66–74

Hardin, P. J., Lulla, V., Jensen, R. R., and Jensen, J. R., (2019), 'Small Unmanned Aerial Systems (sUAS) for environmental remote sensing: challenges and opportunities revisited', *GIScience and Remote Sensing*, **56**(2), p. 309-322

Harris, T., and Lock, G., (1995), 'Toward an evaluation of GIS in European archaeology: the past, present and future of theory and applications', *In:* Lock, G., and Stancic, Z., (eds.), *Archaeology and Geographical Information Systems: A European Perspective*, Taylor & Francis, London, p. 349-366

Hart, C. R., (1981), *The North Derbyshire Archaeological Survey to A.D. 1500*, North Derbyshire Archaeological Trust, Chesterfield

Harwin, S., and Lucieer, A., (2012), 'Assessing the accuracy of georeferenced point clouds produced via Multi-View Stereopsis from Unmanned Aerial Vehicle (UAV) Imagery', *Remote Sensing*, **4**(6), p. 1573-1599

Heath, I. P., Cheetham, P., and Shaw, L., (2013), *Geophysical Survey Report, Arbor Low Environs Project. Gib Hill Barrow, Derbyshire Case #SL00025653 Monument #1011088*, English Heritage Report

Heathcote, J. C., (1940), 'Bronze Age cist from Gib Hill', *Derbyshire Archaeological Journal*, **61**, p. 66-68

Heathcote, J. P., (1957), 'List of Scheduled Ancient Monuments in Derbyshire to 31st December, 1957', *Derbyshire Archaelogical Journal*, **77**, p. 30-37

Hedblom, A., Hedenas, H., Blicharska, M., Adler, S., Knex, I., Mikusinski, G., Svensson, J., Sandstrom, S., Sandstrom, P., and Wardle, D. A., (2019), 'Landscape perception: linking physical monitoring data to perceived landscape properties', *Landscape Research*, p. 1-14

Heidegger, M., (1972), 'Building dwelling thinking', *In:* Kroll, D., (ed.), *Basic Writings*, Routledge, London

Hesse, R., (2010), 'LiDAR-derived Local Relief Models – a new tool for archaeological prospection', *Archaeological Prospection*, **17**, p. 67-72

Hesse, R., (2015), 'Combing Structure-from-Motion with high and intermediate resolution satellite images to document threats to archaeological heritage in arid environments', *Journal of Cultural Heritage*, **16**, p. 192-201

Higham, R., and Barker, P., (1992), *Timber Castles*, Batsford, London

Higuchi, T., (1988), 'The visual and spatial structure of landscapes', MIT Press, Massachusetts

Hill, A. C., (2019), 'Economical drone mapping for archaeology: comparisons of efficiency and accuracy', *Journal of Archaeological Science*, **24**, p. 80-91

Historic England, (2018a), 'Introductions to Heritage Assets: Earthwork and Timber Castles', ONLINE, https://historicengland.org.uk/images-books/publications/iha-earthwork-castles/heag202-earthwork-and-timber-castles/, accessed 6th November 2018, Historic England, Swindon

Historic England, (2018b), 'Prehistoric Henges and Circles: Introductions to Heritage Assets', Swindon, Historic England, ONLINE, https://historicengland.org.uk/images-books/publications/iha-prehistoric-henges-circles/heag218-prehistoric-henges-circles/, accessed 6th November 2018

Historic England, (2018c), ‘Prehistoric Barrows and Burial Mounds: Introductions to Heritage

Historic England, (2018d), ‘Aerial Investigation and Mapping’, ONLINE, https://historicengland.org.uk/research/methods/airborne-remote-sensing/aerial-investigation/, accessed 6th November 2018

Historic England, (2018e), ‘Hot dry summer reveals hidden archaeological sites in England’, ONLINE, https://historicengland.org.uk/whats-new/news/hot-dry-summer-reveals-hidden-archaeological-sites/, accessed 6TH November 2018

Historic England, (2020), ‘Pilsbury Castle Hills motte and bailey castle’, ONLINE, https://historicengland.org.uk/listing/the-list/list-entry/1011199, accessed 11th March 2020

Historic England, (2022a), ‘Arbor Low henge, large irregular stone circle, linear bank and bowl barrow’, ONLINE, https://historicengland.org.uk/listing/the-list/list-entry/1011087?section=official-list-entry, accessed 30th May 2022

Historic England, (2022b), ‘Gib Hill oval and bowl barrow’, ONLINE, https://historicengland.org.uk/listing/the-list/list-entry/1011088?section=official-list-entry, accessed 30th May 2022

Historic England, (2022c), ‘Perry Dale bowl barrow and long barrow’, ONLINE, https://historicengland.org.uk/listing/the-list/list-entry/1009310?section=official-list-entry, accessed 10th August 2022

Historic England, (2022d), ‘White Rake long barrow and bowl barrow’, ONLINE, https://historicengland.org.uk/listing/the-list/list-entry/1010799?section=official-list-entry, accessed 10th August 2022

Historic England, (2023), ‘Drones for Heritage Uses’, ONLINE, https://historicengland.org.uk/research/methods/airborne-remote-sensing/drones/, accessed 8th March 2023

Hobbes, T., (1678), *De mirabilibus pecci: Being the wonders of the peak in Darby-shire, commonly called the devil’s arse of peak, in English and Latine*, London

Hodder, I., (1987), ‘Converging traditions: the search for symbolic meanings in archaeology and geography’, *In:* Wagstaff, J. M., (ed.), *Landscape and culture*, Blackwell, Oxford, p. 134-145

Hodges, R., (1980), ‘Excavations at Camp Green, Hathersage (1976-1977) – a Norman ringwork’, *Derbyshire Archaeological Journal*, **100**, p. 25-34

Hollesen, J., Matthiesen, H., and Elberling, B., (2017), ‘The impact of climate change on an archaeological site in the Arctic’, *Archaeometry*, **59**, p. 1175-1189

Horn, B. K. P., and Brooks, M.J., (1989), *Shape from Shading*, MIT Press, Cambridge, Massachusetts

Hose, T. A., (2017), 'The English Peak District (as a potential geopark): mining geoheritage and historical geotourism', *Acta Geoturistica*, **8**(2), p. 32-49

Howard, A. J., Knight, D., Coulthard, T., Hudson-Edwards, K., Kossoff, D., and Malone, S., (2016), 'Assessing riverine threats to heritage assets posed by future climate change through a geomorphological approach and predictive modelling in the Derwent Valley Mills WHS, UK', *Journal of Cultural Heritage*, **19**, p. 387-394

Howland, M. D., Jones, I. W. N., Najjar, M., and Levy, T. E., (2018), 'Quantifying the effects of erosion on archaeological sites with low-altitude aerial photography, structure from motion, and GIS: A case study from southern Jordan', *Journal of Archaeological Science*, **90**, p. 62-70

Howland, M. D., Tamberino, A., Liritzis, I., and Levy, T. E., (2022), 'Digital deforestation: comparing automated approaches to the production of Digital Term Models (DTMs) in Agisoft Metashape', *Quaternary*, **5**(1), 5

Howley, P. (2011), 'Landscape aesthetics: Assessing the general publics' preferences towards rural landscapes', *Ecological Economics*, **72**, p. 161–169

Howley, P., Hynes, S., O Donoghue, C., (2010), 'The citizen versus consumer distinction: an exploration of individuals' preferences in contingent valuation studies', *Ecological Economics*, **69**, p. 1524–1531

Huggett, R., (2020), 'The Peak District', *In:* Goudie, A., and Migon, P., (eds.), *Landscapes and Landforms of England and Wales*, Springer, p. 393-416

Huh, C. and Singh, A.J., (2007), 'Families travelling with a disabled member: Analysing the potential of an emerging niche market segment', *Tourism and Hospitality Rese*arch, **7**(3-4), p. 212-229

Hunt, E. D., (1992), 'Upgrading site catchment analyses with the use of GIS: investigating the settlement patterns of horticulturalists', *World Archaeology*, **24**(2), p. 283-309

Hunziker, M., Buchecker, M., & Hartig, T., (2007), 'Space and place - Two aspects of the human-landscape relationship', *In:* F. Kienast, O. Wildi & S. Ghosh, (eds.), *A changing world. Challenges for landscape research,* Springer, Dordrecht, p. 47-62

Ilci, V., Ozulu, I. M., Bilgi, S., and Alkan, R. M., (2019), 'The usage of unmanned aerial vehicles (UAVs) for 3D mapping of archaeological sites', *Fresenius Environmental Bulletin*, **28**(2), p. 968-974

Ingold, T., (1992), 'Perception of the Environment', *In:* Croll, E., and Parkin, D., (eds.), *Bush Base: Forest Farm – culture, environment and development*, p. 39-56, Routledge, London

Inzerillo, L., Di Paola, F., Alogna, Y. and Roberts, R. A., (2020), 'Optimisation of Cultural Heritage Virtual Environments for Gaming Applications', *In:* Arai, K., Kapoor, S., and Bhatia, R., (eds.), *Advances in Information and Communications: Proceedings of the 2020 Future of Information and Communication Conference (FICC)*, p. 353-371, Cham, Springer

Jackson, J. B., (1984), *Discovering the Vernacular Landscape*, Yale University Press, New Haven, Connecticut

Janowski, J., (2015), 'Bamiyan, vandalism, and the sublime', *Change Over Time*, **5**(1), p. 28-64

Jantke, K., P., (2010), 'Toward a taxonomy of game based learning', *In:* Proceedings of the 1st IEEE International Conference on Progress in Informatics and Computing (PIC '10), **2**, p. 858–862

Jeayes, I. W., (1906), *Descriptive Catalogue of Derbyshire Charters*, Bemrose & Son, London

Jones, K. H., (1998), 'A comparison of algorithms used to compute hill slope as a property of the DEM', *Computers and Geosciences*, **24**(4), p. 315-323

Jones, N., and McGInlay, J., (2020), 'The impact of COVID-19 restrictions on local communities of the Peak District National Park and management options during the pandemic', University of Cambridge Conservation Research Institute and Department of Land Economy

Kalacska, M., Lucanus, O., Arroyo-Mora, J. P., Laliberte, E., Elmer, K., Leblanc, G., and Groves, A., (2020), 'Accuracy of 3D Landscape Reconstruction without Ground Control Points Using Different UAS Platforms', *Drones*, **4**(2), Article No. 13

Keele University, (2018), 'Heatwave Reveals Medieval Road in Keele', ONLINE, https://www.keele.ac.uk/discover/news/august/heatwave-reveals/medieval-road-keele.php, accessed 27th November 2018

Kender, J. R., (1981), 'Shape from Texture', Carnegie Mellon University, Pittsburgh, Pennsylvania

Khalaf, R.W., (2018), 'World Heritage policy on reconstruction: from exceptional case to conservation treatment', *International Journal of Cultural Policy*, p. 1-15.

Kienast, F., Frick, J., van Strien, M. J., and Hunziker, M., (2015), 'The Swiss landscape monitoring program – A comprehensive indicator set to measure landscape change', *Ecological Modelling*, **295**, p. 136-150

Kim, M.J., and Hall, C. M., (2019), 'A hedonic motivation model in virtual reality tourism: comparing visitors and non-visitors', *International Journal of Information Management,* **46**, p. 236–249

Kokalj, Z., Zaksek, K., and Ostir, K., (2011), 'Application of sky-view factor for the visualisation of historic landscape features in LIDAR-derived relief models', *Antiquity*, **85**, p. 263-273

Koller, D., Frischer, B., and Humphreys, G., (2009), 'Research challenges for digital archives of 3D cultural heritage models', *Journal on Computing and Cultural Heritage*, **2**(3), p. 1-17

Kosmas, P., Galanakis, G., Constantinou, V., Drossis, G., Christofi, M., Klironomos, I., Zaphiris, P., Antona, M., and Stephanidis, C., (2020), 'Enhancing accessibility in cultural heritage environments: considerations for social computing', *Universal Access in the Information Society,* **19**(2), p. 471-482

Koutsoudis, A., Vidmar, B., Ioannakis, G., Arnaoutoglou, F., Pavlidis, G., and Chamzas, C., (2014), 'Multi-image 3D reconstruction data evaluation', *Journal of Cultural Heritage*, **15**(1), p. 73-79

Kvamme, K. L., (1989), 'Geographic Information Systems in Regional Archaeological Research and Data Management', *In:* Schiffer, M. B., (ed.), *Method and Theory in Archaeology*, **1**, p. 13-203, University of Arizona Press, Tucson

Kvamme, K., (1999), 'Recent directions and developments in Geographical Information Systems' *Journal of Archaeological Research*, **7**(2), p. 49-57

Kvamme, K.L., (1993), *Spatial statistics and GIS: An integrated approach*, Aarhus: Aarhus Iiniversity Press, CAA, 92

Laamarti, F., Eid, M., and El Saddik, A., (2014), 'An Overview of Serious Games', *International Journal of Computer Games Technology,* p. 1-15

Lai, L., and Sordini, M., (2013), '3D documentation of a megalithic building in Sardinia', *CHNT 18 Proceedings – International Conference on Cultural Heritage and New Technologies*, Vienna

Landeschi, G., (2018), 'Rethinking GIS, three-dimensionality and space perception in archaeology', *World Archaeology*, p. 1-16

Land-Info, (2018), 'Buying Satellite Imagery: Pricing information for High Resolution Satellite Imagery', ONLINE, http://www.landinfo.com/satellite-imagery-pricing.html, accessed 21st November 2018

Landon, N., Ash, P., Payne, A., Phillips, G., (2006), 'Pilsbury: A Forgotten Castle', *Derbyshire Archaeological Journal*, **126,** p. 82-102

Landsat, (2019), 'Landsat Science', ONLINE, https://landsat.gsfc.nasa.gov/, accessed 21st March 2019

Laporte-Fauret, Q., Marieu, V., Castelle, B., Michalet, R., Bujan, S., and Roseberry, D., (2019), 'Low-cost UAV for high-resolution and large-scale coastal dune change monitoring using photogrammetry', *Journal of Marine Science and Engineering*, **7**(3), Article No. 63

Lastilla, L., Belloni, V., Ravanelli, R., and Crespi, M., (2021), 'DSM Generation from Single and Cross-Sensor Multi-View Satellite Images Using the New Agisoft Metashape: The Case Studies of Trento and Matera (Italy)', *Remote Sensing*, **13**, Article No. 593

Lee, H., Jung, T. H., tom Dieck, M. C., and Chung, N., (2020), ‘Experiencing immersive virtual reality in museums’, *Information and Management*, **57**(5), 103229

Lepper, B. T., Duncan, J. R., Diaz-Granados, C., and Frolking, T., A., (2018), ‘Arguments for the Age of the Serpent Mound’, *Cambridge Archaeological Journal*, **28**(3), p. 433-450

Lerma, J. L., Navarro, S., Cabrelles, M., and Villaverde, V., (2010), ‘Terrestrial laser scanning and close range photogrammetry for 3D archaeological documentation: the Upper Palaeolithic Cave of Parpalló as a case study’, *Journal of Archaeological Science*, **37**(3), p. 499-507

Lin, J.J., Mamykina, L., Lindtner, S., Delajoux, G. and Strub, H.B., (2006), ‘Fish’n’Steps: Encouraging physical activity with an interactive computer game’, *International conference on ubiquitous computing*, p. 261-278, Springer, Berlin, Heidelberg

Lindner, G., Schraml, K., Mansberger, R., and Hubl, J., (2015), ‘UAV monitoring and documentation of a large landslide’, *Applied Geomatics*, **8**(1), p. 1-11

Llobera, M., (1996), ‘Exploring the topography of mind: GIS, social space and archaeology’, *Antiquity*, **70**(269), p. 612-622

Llobera, M., (2001), ‘Building past landscape perception with GIS; Understanding Topographic Prominence’, *Journal of Archaeological Science*, **28**, p. 1005-1014

Lock, G., and Pouncett, J., (2017), ‘Spatial thinking in archaeology: is GIS the answer?’, *Journal of Archaeological Science*, **84**, p. 129-135

London Charter, (2009), ONLINE, http://www.londoncharter.org/introduction.html, accessed 12th February 2019

Lowenthal, D., (1985), ‘The Past is a Foreign Country’, Cambridge University Press, Cambridge

Lu, J., Xiao, X., Xu, Z., Wang, C., Zhang, M. and Zhou, Y., (2022), ‘The potential of virtual tourism in the recovery of tourism industry during the COVID-19 pandemic’, *Current Issues in Tourism*, **25**(3), p. 441-457

Lužnik, N., and Klein, M., (2015), ‘Interdisciplinary Workflow for Virtual Archaeology’, *Digital Heritage*, p. 177-180

Lynch, K. (1960), *The Image of the City*, Cambridge, Technology Press

Macpherson, H., (2009), ‘The intercorporeal emergence of landscape: negotiating sight, blindness, and ideas of landscape in the British countryside’, *Environment and planning A*, **41**(5), p. 1042-1054

Macpherson, H., (2017), ‘Walker with visual-impairment in the British countryside: Picturesque legacies, collective enjoyments and well-being benefits’, *Journal of Rural Studies*, **51**, p. 251-258

Madry, S. L. H., and Crumley, C. L., (1990), ‘An application of remote sensing and GIS in a regional archaeological settlement pattern analysis: the Arroux River valley, Burgundy, France’, *In:* Allen, K. M. S., Green, S. W., and Zubrow, E. B. W., (eds.), *Interpreting Space: GIS and archaeology,* Taylor & Francis, London, p. 364-380

Magnani, M., and Schroder, W., (2015), ‘New approaches to modelling the volume of earthen archaeological features: A case-study from the Hopewell culture mounds’, *Journal of Archaeological Science*, **64**, p. 12-21

Majewski, J., and Bunch, L., (1998), ‘The expanding definition of diversity: accessibility and disability culture issues in museum exhibitions’, *Curator The Museum Journal*, **41**(3), p. 153-160

Malbon, H., (2017), ‘Using UAV Photogrammetry for Cultural Heritage Sited 3D Modelling, Reconstruction and Analysis: Arbor Low’, Unpublished Master’s thesis, Keele University, Keele, Staffordshire, UK

Manžuch, Z., (2017), ‘Ethical issues in digitization of cultural heritage,’ *Journal of Contemporary Archival Studies*, **4**(2), p. 1-17

Marasco, A. and Balbi, B., (2019), ‘Designing accessible experiences for heritage visitors through virtual reality’, *E-review of Tourism Research*, **17**(3), p. 426-443

Marble, D. F., (1990), ‘The potential methodological impact of geographic information systems on the social sciences’, *In:* Allen, K. M. S., Green, S. W., and Zubrow, E. B. W., (eds.), *Interpreting Space: GIS and archaeology*, Taylor & Francis, London

Mariam, H., (2009), ‘The cultural benefits of the return of the Axum Obelisk’, *Museum International*, **61**(1-2), p. 48-51

Marmion, M., Wilkes, K. & Calver, S. (2009), ‘Heritage? What do you mean by heritage?’, *In*: Lira, S S., Arnoeda, R., Pinheiro, C., Pinheiro, J., and Oliveira, F., (eds.), *Sharing Cultures 2009, International Conference on Intangible Heritage*, Green Lines Institute, Barcelos, Portugal, p. 575–584

Marsden, B. M., (1999), *The Early Barrow Diggers*, Tempus, Stroud

Martens, H., (1890), *Optishes Mass für den Stadtebau*, Max Cohn & Son, Bonn

Martin, L., (2001), *Arbor Low, Derbyshire: Report on Geophysical Survey, August 1998*, Centre for Archaeology Report 80/2001, English Heritage, Portsmouth

Mascari, G. F., Mautone, M., Moltedo, L., and Salonia, P., (2009), ‘Landscapes, Heritage and Culture’, *Journal of Cultural Heritage*, **10**, p. 22-29

Matikainen, L., Lehtomaki, M., Ahokas, E., Hyyppa, J., Karjalainen, M., Jaakkola, A., Kukko, A., and

McGuire, S., and Smith, K., (2008), ‘Arbor Low and Gib Hill Conservation Plan 2008’, Peak District National Park Authority & English Heritage, United Kingdom

McNeary, R. W. A., (2014), 'Lidar investigation of Knockdhu Promontory and its Environs, Country Antrim, Northern Ireland', *Archaeological Prospection*, **21**, p. 263-276

McOmish, D., and Tuck, C., (2002), *Long Low Bank Barrow, Ilam Staffordshire*: *Archaeological Investigation Report Series 41/2002*, English Heritage, Swindon

Merleau-Ponty, M., (1962), 'Phenomenology of Perception', Routledge, London

Meyer, D., Fraijo, E., Lo, E., Rissolo, D., and Kuester, F., (2015), 'Optimizing UAV Systems for Rapid Survey and Reconstruction of Large Scale Cultural Heritage Sites', *In:* 2015 Digital Heritage, *IEEE,* **1**, p. 151-154

Michael, D. R., and Chen, S. L., (2005), *Serious games: games that educate, train and inform*, Muska and Lipman/Premier-Trade

Michaud, L., (2010), 'Serious games, A 10 billion Euro market in 2015', IDATE

Microsoft, (2019), 'About', ONLINE, https://www.microsoft.com/en-gb/about/, accessed 21st March 2019

Miles, H. C., Wilson, A. T., Labrosse, F., Tiddeman, B., Griffiths, S., Edwards, B., Ritsos, P. D., Mearman, J. W., Moller, K., Karl, R., and Roberts, J. C., (2015), 'Alternative representations of 3D-reconstructed heritage data', *ACM Journal on Computing and Cultural Heritage*, **9**(1), p. 1-18

Miller, P., and Richards, J., (1995), 'The good, the bad, and the downright misleading: archaeological adoption of computer visualisation', *In:* Huggett, J., and Ryan, N., (eds.), *Computer applications in archaeology. International Series 600*, British Archaeological Report/Tempus Reparatum, Oxford, p. 19-22

Mlekuz, D., (2010),'Time geography, GIS and archaeology', *In: Fusion of Cultures. Abstracts from the 38th Conference on Computer Applications and Quantitative Methods in Archaeology*, University of Granada, CAA Inernational, p. 443-445

Mohsan, S. A. H., Khan, M. A., Noor, F., Ullah, I., and Alsharif, M. H., (2022), 'Towards the Unmanned Aerial Vehicle (UAVs): A comprehensive review', *Drones,* **6**(6), p. 147

Montufo, A. M., (1997), 'The use of satellite imagery and digital image processing in landscape archaeology. A case study from the island of Mallorca, Spain', *Geoarchaeology: An International Journal*, **12**(1), p. 71-85

Mortara, M., and Catalano, C. E., (2018), '3D Virtual environments as effective learning contexts for cultural heritage', *Italian Journal of Educational Technology*, **26**(2), p. 5-21

Muenster, S., (2022), 'Digital 3D Technologies for Humanities Research and Education: An Overview', *Applied Sciences*, **12**(5), Article No. 2426

Munjeri, D. (2004), 'Tangible and intangible heritage: From difference to convergence', *Museum 221- 222*, **56**(1–2), p. 12–20

National Trust, (2022), 'Explore virtual ruins in Minecraft', ONLINE, https://www.nationaltrust.org.uk/features/explore-virtual-ruins-in-minecraft, accessed 23rd August 2022

Natural England, (2019), 'Monitor of Engagement with the Natural Environment: Headline report and technical reports 2018 to 2019', ONLINE, https://www.gov.uk/government/statistics/monitor-of-engagement-with-the-natural-environment-headline-report-and-technical-reports-2018-to-2019, accessed 21st August 2022

Nesbit, P. R., Durkin, P. R., Hugenholtz, C. H., Hubbard, S. H., and Kucharczyk, M., (2018), '3-D stratigraphic mapping using a digital outcrop model derived from UAV images and structure-from-motion photogrammetry', *Geosphere*, **14**(6), p. 2469-2486

Neumüller, M., Reichinger, A., Rist, F., & Kern, C., (2014), '3D printing for cultural heritage: Preservation, accessibility, research and education'. *In:* 3D Research Challenges in Cultural Heritage, p. 119-134, Springer, Berlin, Heidelberg.

Nex, F., and Remondino, F., (2013), 'UAV for 3D mapping applications: a review', *Applied Geomatics*, **6**(1), p. 1-15

Niederheiser, R., Mokros, M., Lange, J., Petschko, H., Prasicek, G., and Oude Elberink, S. O., (2016), 'Deriving 3D Point Clouds from Terrestrial Photographs Comparison of Different Sensors and Software', *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, **41**, p. 685-692

Nikolakopoulous, K. G., Soura, K., Koukouvelas, I. K., and Argyropoulos, N. G., (2017), 'UAV vs classical aerial photogrammetry for archaeological studies', *Journal of Archaeological Science: Reports*, **14**, p. 758-773

Nobajas, A., Waller, R. I., Robinson, Z. P., and Sangonzalo, R., (2017), 'Too much of a good thing? The role of detailed UAV imagery in characterizing large-scale badland drainage characteristics in South-Eastern Spain', *International Journal of Remote Sensing*, **38**(8-10), p. 2844-2860

O'Driscoll, J., (2018), 'Landscape applications of photogrammetry using unmanned aerial vehicles', *Journal Archaeological Science: Reports*, **22**, p. 32-44

O'Drsicoll, J., (2017), 'Hillforts in prehistoric Ireland: a costly display of power?', *World Archaeology*, **49**(4), p. 506-525

Opitz, R. S., (2013), ‘An Overview of Airborne and Terrestrial Laser Scanning in Archaeology’, *In*: Opitz, R. S., and Cowley, D. C., (eds.), *Interpreting Archaeological Topography*, Oxford Books, Oxford, UK, p. 13–31

Orozco, M., Silva, J., El Saddik, A. and Petriu, E., (2012), ‘The role of haptics in games’, *Haptics rendering and applications*, p. 217-234

Osterman, A., (2014), ‘Map visualization in ArcGIS, QGIS and MapInfo’, Degree Project, KTH Royal Institute of Technology, Stockholm

Ott, M., and Pozzi, F., (2011), ‘Towards a new era for Cultural Heritage Education: Discussing the role of ICT’, *Computers in Human Behavior*, **27**(4), p. 1365-1371

Paladini, A., Dhanda, A., Reina Ortiz, M., Weigert, A., Nofal, E., Min, A., Gyi, M., Su, S., Van Balen, K. and Santana Quintero, M., (2019), ‘Impact of virtual reality experience on accessibility of cultural heritage’, *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, **42**(W11), p.929-936

Pape, R., (2008), ‘The Young Body of Christ: the Contribution to Youth Work in Primitive Methodism by Joseph Wood, the First Agent of its Connexional Sunday School Union’, *Heritage; Bulletin of the East Midlands Branch of the Wesley Historical Society*, **9**(1), p. 4-27

Parker, A., (2013), ‘Document Title: Hallstead, Dove Holes, Buxton’, ONLINE, https://library.thehumanjourney.net/4387/1/Hallstead%20shovel%20test%20pit%20eval%20060813.pdf, accessed 27th June 2022

Parsons, D. N., and Styles, T., (2000), *The Vocabulary of English Place Names; Brace-Caestor*, Centre for English Names Studies, Nottingham

Pauwels, P., Verstraeten, R., De Meyer, R., & Van Campenhout, J. (2008), ‘Architectural Information Modelling for Virtual Heritage Application,’ *In:* Ioannides, M., Addison, A., Georgopoulos, A., and Kalisperis, L., (eds.), *Digital Heritage–Proceedings of the 14th International Conference on Virtual Systems and Multimedia, Archaeolingua,* Budapest, Hungary, p. 18-23

Peak District National Park (PDNPA), (2022), ‘Archaeology’, ONLINE, https://www.peakdistrict.gov.uk/learning-about/archaeology, accessed 4th July 2022

Peak District National Park Authority (PDNPA), (2014), ‘Peak District National Park Visitor Survey 2014 & Non-Visitor Survey 2014’, ONLINE, https://www.peakdistrict.gov.uk/__data/assets/pdf_file/0030/63876/Vistor-and-Non-Visitor-Survey.pdf, accessed 29th April 2020

Peak District National Park Authority (PDNPA), (2020a), 'Media Centre Facts and Figures', ONLINE, https://www.peakdistrict.gov.uk/learning-about/news/mediacentrefacts, accessed 29th January 2020

Peak District National Park Authority (PDNPA), (2020b), 'About the National Park', ONLINE, https://www.peakdistrict.gov.uk/learning-about/about-the-national-park, accessed 29th January 2020

Peak District National Park Authority (PDNPA), (2020c), 'South West Peak', ONLINE, https://www.peakdistrict.gov.uk/__data/assets/pdf_file/0014/48002/south-west-peak-description.pdf, accessed 19th February 2020

Peak District National Park Authority (PDNPA), (2020d), 'The Dark Peak', ONLINE, https://www.peakdistrict.gov.uk/__data/assets/pdf_file/0036/47997/dark-peak-description.pdf , accessed 19th February 2020

Peak District National Park Authority (PDNPA), (2020e), 'White Peak', ONLINE, https://www.peakdistrict.gov.uk/looking-after/biodiversity/biodiversity-action-plan/white-peak, accessed 19th February 2020

Peak District National Park Authority (PDNPA), (2020f), 'The White Peak', ONLINE, https://www.peakdistrict.gov.uk/__data/assets/pdf_file/0012/48000/white-peak-description.pdf, accessed 19th February 2020

Peak District National Park Authority (PDNPA), (2020g), 'Pilsbury Castle Trail – from Hartington Centuries of Settlement', ONLINE, https://www.peakdistrict.gov.uk/__data/assets/pdf_file/0015/500631/Hartington.pdf, accessed 11th March 2020

Pedersen, A., (2002), *Managing Tourism at World Heritage Sites: a Practical Manual for World Heritage Site Managers*, UNESCO World Heritage Centre, Paris

Pegge, Rev., (1785), 'A Disquisition on the Lows or Barrows in the Peak of Derbyshire, particularly that capital British Monument called Arbelows', *Archaeologia*, **7**, p. 131-148

Pfarr-Harfst, M., (2016), 'Typical workflows, documentation approaches and principles of 3D digital reconstruction and heritage', *In:* Münster, S., Pfarr-Harfst, M., Kuroczyński, P., & Ioannides, M., (eds.*), 3D research challenges in cultural heritage II: How to manage data and knowledge related to interpretative digital 3D reconstructions of cultural heritage*, Cham, Switzerland: Springer International Publishing, p. 32-47

Pinter, T. L., (2005), 'Heritage Tourism and archaeology: Critical issues', *The SAA Archaeological Record*, **5**(3), p. 9-11

Pitney Bowes, (2019), ‘MapInfo® Pro v17 Advanced’, ONLINE, https://www.pitneybowes.com/us/location-intelligence/geographic-information-systems/mapinfo-pro-advanced.html, accessed 11th June 2019

Pletinckx, D., (2009), ‘Virtual archaeology as an integrated preservation method’, *Virtual Archaeology Review*, **2**(4), p. 33-37

Primicerio, J., Di Gennaro, S. F., Fiorillo, E., Genesio, L., Lugato, E., Matese, A., and Vaccari, E. P., (2012), ‘A flexible unmanned aerial vehicle for precision agriculture’, *Precision Agriculture*, **13**, p. 517-523

Pryor, F., (2004), *Britain BC: Life in Britain and Ireland before the Romans*, (2nd ed.), Harper Perennial, London

Przybilla, H. J., Lindstaedt, M., and Kersten, T., (2019), ‘Investigations into the quality of image-based point clouds from UAV imagery’, *In: ISPRS Geospatial Week 2019, 10–14 June 2019,* Enschede, The Netherlands*,* Copernicus, p. 539-545

Puliti, S., Orka, H. O., Gobakken, T., and Naesset, E., (2015), ‘Inventory of small forest areas using an Unmanned Aerial System’, *Remote Sensing*, **7**, p. 9632-9654

QGIS, (2019), ‘About QGIS’, ONLINE, https://www.qgis.org/en/site/about/index.html, accessed 11th June 2019

Quan Li, X., an Chen, Z., ting Zhang, L., and Jia, D., (2016), ‘Construction and Accuracy Test of a 3D Model of Non-Metric Camera Images Using AgiSoft PhotoScan’, *Procedia Environmental Sciences*, **36**, p. 184-190

QuestUAV, (2019), ‘Fixed wing versus rotary wing UAV for mapping applications’, ONLINE, https://www.questuav.com/media/case-study/fixed-wing-versus-rotary-wing-for-uav-mapping-applications/, accessed 18th June 2019

Radley, J., (1968), ‘The Origin of Arbor Low Henge Monument’, *the Derbyshire Archaeological Journal,* **88**, p. 100-103

Ralston, I., (2006), *Celtic Fortifications*, Tempus, Stroud

Rapp, G. C., (2009), ‘Unmanned Aerial Exposure: Civil Liability Concerns Arising from Domestic Law Enforcement Employment of Unmanned Aerial Systems’, *North Dakota Law Review*, p. 623-648

Rassmann, C., (2010), ‘Identities overseas? The long barrows in Denmark and Britain’, *Journal of Neolithic Archaeology*, **12**(2), p. 1-16

Ravan, M., Revez, M. J., Pinot, I. V., Brum, P., and Birkmann, J., (2023), ‘A vulnerability assessment framework for Cultural Heritage Sites: the case of the Roman ruins of Troia’, *International Journal of Disaster Risk Science*, p. 1-15

Reilly, P., (1991), 'Towards a Virtual Archaeology,' *In:* Rahtz, S., and Lockyear, K. (eds.), *Computer Applications and Quantitative Methods in Archaeology*, British Archaeological Reports International Series, **565**, p. 132-139

Remondino, F., (2011), 'Heritage recording and 3D modelling with photogrammetry and 3D scanning', *Remote Sensing*, **3**, p. 1104-1138

Remondino, F., and El-Hakim, S., (2006), 'Image-Based 3D Modelling: A Review', *The Photogrammetric Record*, **21**(115), p. 269-291

Remondino, F., Grazia Spera, M., Nocerino, E., Menna, F., and Nex, F., (2014), 'State of the Art in High Density Image Matching', *Photogrammetric Record*, **29**(146), p. 144-166

Renfrew, C., (1969), 'Review of "Locational Analysis in Human Geography" by P. Haggett', *Antiquity*, **43**, p. 74-75

Renfrew, C., Chesterman, J. T., and Aitken, M. J., (1979), Investigations in Orkney: *Reports of the Research Committee of the Society of Antiquaries of London*, London

Richards-Rissetto, H., Remondino, F., Robersson, J., von Schwerin, J., Agugiaro, G., and Girardi, G., (2012), 'Kinect and 3D GIS in archaeology', *Anthropology Faculty Publications*, **63**, p. 331-337

Rinaudo, F., Chiabrando, F., Lingua, A., and Spano, A. T., (2012), 'Archaeological site monitoring: UAV photogrammetry can be an answer', *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, **39**(B5), p.583-588

Risbol, O., and Gustavsen, L., (2018), 'LiDAR from drones employed for mapping archaeology – Potential, benefits and challenges', *Archaeological Prospection*, p. 1-10

Rock, I., and Palmer, S., (1990), 'The legacy of Gestalt psychology', *Scientific American,* **263**(6), p. 84-91

Rogers, A. J., (2013), 'The afterlife of monuments in the English Peak District: the evidence of early Bronze Age burials', *Oxford Journal of Archaeology*, **32**(1), p. 39-51

Roussin, L. A. (2003), 'Cultural heritage and identity', *Cardozo Journal of International and Comparative Law*, **11**(2), p. 707-710

Rowley, T., (1983), *The Norman Heritage*, Routledge & Kegan Paul, London

Rua, H., and Alvito, P., (2011), 'Living the past: 3D models, virtual reality and game engines as tools for supporting archaeology and the reconstruction of cultural heritage - the case-study of the Roman villa of Casal de Freiria', *Journal of Archaeological Science*, **38**(12), p. 3296-3308

Saad, A. M., and Tahar, K. N., (2019), 'Identification of rut and pothole by using multirotor unmanned aerial vehicle (UAV), *Measurement*, **137**, p. 647-654

Saeed, A. S., Younes, A. B., Cai, C., and Cai, G., (2018), 'A survey of hybrid Unmanned Aerial Vehicles', *Progess in Aerospace Sciences*, **98**, p. 91-105

Saeed, A. S., Younes, A. B., Islam, S., Dias, J., Seneviratne, L., and Cai, G., (2015), ‘A review on the platform design, dynamic modelling and control of Hybrid UAVs’, *2015 International Conference on Unmanned Aircraft Systems (ICUAS)’,* p. 806-815, IEEE

Salach, A., Bakula, K., Pilarska, M., Ostrowski, W., Gorski, K., and Kurczynski, Z., (2018), ‘Accuracy assessment of point clouds from LiDAR and Dense Image Matching acquired using the UAV platform for DTM creation’, *ISPRS International Journal of Geo-Information*, **7**(9), p. 342

Sanders, D., (2014), ‘More than pretty pictures of the past; an American perspective on virtual heritage’, *In:* Bentkowski-Kafel, A., Denard, H., and Bake, D., (eds.), *Paradata and Transparency in Virtual Heritage*, Routledge, p. 37-56

Sandia LLC, (2018), ‘What is Synthetic Aperture Radar (SAR)?’, ONLINE, https://www.sandia.gov/radar/what_is_sar/, accessed 21st November 2018

Santos, P., Ritz, M., Fuhrmann, C., and Fellner, D., (2016), ‘3D mass digitization: a milestone for archaeological documentation’, *Virtual Archaeology Review*, **8**(16), p. 1-11

Sapirstein, P., (2016), ‘Accurate measurement with photogrammetry at large sites’*, Journal of Archaeological Science*, **66**, p. 137-145

Satellite Imaging Corporation, (2017), ‘IKONOS Satellite Sensor (0.82m) – Decommissioned’, ONLINE, https://www.satimagingcorp.com/satellite-sensors/ikonos/, accessed 21st November 2018

Savage, S. H., (1990), ‘GIS in archaeological research’, *In:* Allen, K. M. S., Green, S. W., and Zubrow, E. B. W., (eds.), ‘*Interpreting Space: GIS and archaeology’,* Taylor & Francis,

Sawyer, B., and Rejeski, D., (2002), *Serious games: improving public policy through game-based learning and simulation*, Woodrow Wilson International Centre for Scholars

Scharf, E.A., (2014), ‘Deep time: the emerging role of archaeology in landscape ecology’, *Landscape Ecology*, **29**(4), p. 563-569

Scheinsohn, V., and Matteucci, S., (2004), ‘Spaces and species: archaeology, landscape ecology and spatial models in northern Patagonia’, *Before Farming*, **2004**(1), p. 1-12

Schiffer, M. A., Sullivan, A., and Klinger, T., (1978), ‘The Design of Archaeological Surveys’, *World Archaeology*, **10**(1), p. 1-28

Schwind, M., and Starek, M. J., (2017), ‘Assessing 3D Point Cloud Fidelity of UAS- SfMSoftware Solutions over Varying Terrain’, *In:* 18th Annual JALBTCX Airborne Coastal Mapping and Charting Technical Workshop

Scopigno, R., Cignoni, P., Pietroni, N., Callieri, M., and Dellepiane, M., (2017), ‘Digital fabrication techniques for cultural heritage: a survey’, *Computer Graphics*, **36**(1), p. 6-21

Seitz, S. M., Curless, B., Diebel, J., Scharstein, D., and Szeliski, R., (2006), ‘A comparison and evaluation of multi-view stereo reconstruction algorithms’, *In:* 2006 IEEE computer society conference on computer vision and pattern recognition (CVPR’06), *IEEE* (eds.), **1**, p. 519-528, ONLINE, https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=1640800, accessed 21st March 2019

Shadiev, R., and Yi, S., (2022), ‘A systematic review of UAV applications to education’, *Interactive Learning Environments*, p. 1-30

Shanks, M., and Tilley, C., (1992), *Reconstructing Archaeology: Theory and practic*e, (2nd ed.), Routledge, London

Siart, C., Eitel, B., and Panagiotopoulos, D., (2008), ‘Investigation of past archaeological landscapes using remote sensing and GIS: a multi-method case stufy from Mount Ida, Crete’, *Journal of Archaeological Science*, **35**(11), p.2918-2926

Simpson, J. E., Smith, T. E. L., and Wooster, M. J., (2017), ‘Assessment of Errors Caused by forest vegetation structure in airborne LiDAR-Derived DTMs’, *Remote Sensing,* **9**(11), 1101

Sims, D., (1997), ‘Archaeological models: pretty pictures or research tools?’, *IEEE Computer Graphics*, **17**(1), p. 13-15

Skidmore, A. K., (1989), ‘A comparison of techniques for calculating gradient and aspect from a gridded digital elevation model’, *International Journal of Geographical Information Systems*, **3**(4), p. 323-334

Smith, L. (2006), *Uses of Heritage*, Routledge, London

Smith, M. W., Carrivick, J. L., and Quincey, D. J., (2016), ‘Structure from motion photogrammetry in physical geography’, *Progress in Physical Geography*, **40**(2), p. 247-275

Sokolowski, R., (2000), *Introduction to phenomenology*, Cambridge University Press, Cambridge

Soler, F., Melero, F. J., and Luzon, M. V., (2017), ‘A complete 3D information system for cultural heritage documentation’, *Journal of Cultural Heritage*, **23**, p. 40-57

Sozzi, M., Kayad, A., Gobbo, S., Cogato, A., Sartori, L. and Marinello, F., (2021), ‘Economic comparison of satellite, plane and uav-acquired NDVI images for site-specific nitrogen application: Observations from Italy’, *Agronomy*, **11**(11), p.2098

Squier, E., and Davis, E., (1848), Ancients monuments of the Mississippi Valley, Smithsonian Institution, Washington (DC)

Stal, C., Lonneville, B., Nuttens, T., de Maeyer, P., and de Wulf, A., (2014), ‘Highly detailed 3D modelling of Mayan Cultural Heritage using an UAV’, *25th FIG Congress: Enhancing the challenges, enhances the relevance*, p. 1-14

Statham, N. (2019), ‘Scientific rigour of online platforms for 3D visualisation of heritage’, *Virtual Archaeology Review,* **10**(20), p. 1-16

Stedman, R. C., (2008), ‘What do we ‘‘mean’’ by place meanings? Implications of place meanings for managers and practitioners’, *In*: Kruger, L. E., Hall, T., and Stiefel, M. C., (eds.), *Understanding concepts of place in recreation research and management*, General Technical Report PNW-GTR-744, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, Oregon, p. 61–82

Stek, T. D., (2016), ‘Drones over Mediterranean landscapes. The potential of small UAV’s (drones) for site detection and heritage management in archaeological survey projects: A case study from Le Pianelle in the Tappino Valley, Molise (Italy)’, *Journal of Cultural Heritage*, **22**, p. 1066-1071

Strumse, E., (1994), ‘Perceptual dimensions in the visual preferences for agrarian landscapes in western Norway’, *Journal of Environmental Psychology*, **14**, p. 281-292

Sullivan, E. (2016), ‘Potential pasts: Taking a humanistic approach to computer visualization of ancient landscapes’, *Bulletin of the Institute of Classical Studies,* **59**(2), p. 71-88

Sullivan, E. A., and Snyder, L. M. (2017). Digital Karnak. *Journal of the Society of Architectural Historians, 76*(4), p. 464-482

Susam, T., (2017), ‘Topographical analyses of Unmanned Aerial Vehicle-based very high-resolution Digital Surface Models for archaeological sites’, *Tehnicki vjesnik*, **26**(1), p. 236-242

Svensson, J., and Andersson, A. (2018), ‘Photogrammetric 3d-mapping using low-cost unmanned aerial vehicle-Analysis of accuracy’, Unpublished Master’s thesis, Lund University, Lund, Sweden

Swensen, G., Jerpasen, G. B., Saeter, O., and Tveit, M. S., (2013), ‘Capturing the Intangible and Tangible Aspects of Heritage: Personal versus Official Perspectives in Cultural Heritage Management’, *Landscape Research*, **38**(2), p. 203-221

Taddia, Y., Gonzalez-Garcia, L., Zambello, E., and Pellegrinelli, A., (2020), ‘Quality Assessment of Photogrammetric Models for Façade and Building Reconstruction Using a DJI Phantom 4 RTK’, *Drones*, **12**(19), 3144

Tahar, K., N., and Ahmad, A., (2012), ‘An evaluation on fixed wing and multi-rotor UAV images using Photogrammetric Image Processing’, *International Journal of Computer and Information Engineering*, **7**(1), p. 1300-1306

Tan, P., (2014), ‘Image-Based Modelling’, *In:* Ikeuchi, K., (ed.), *Computer Vision*, Springer, Boston

Tempesta, T., (2010), ‘The perception of agrarian historical landscapes: a study of the Veneto plain in Italy’, *Landscape and Urban Planning*, **97**(4), p. 258-272

Themistocleous, K., (2020), ‘The Use of UAVs for Cultural Heritage and Archaeology’, *In:* Remote Sensing for Archaeology and Cultural Landscapes, p. 241-269, Springer, Cham

Themistocleous, K., Ioannides, M., Agapiou, A., and Hadjimitsis, D. G., (2015), ‘The methodology of documenting cultural heritage sites using photogrammetry, UAV, and 3D printing techniques: the case study of Asinou Church in Cyprus’, *Third International Conference on Remote Sensing and Geoinformation of the Environment*, **9535**

Thomas, J., (1993), ‘The politics of vision and the archaeologies of landscape’, *In;* Bender, B., (ed.), *Landscape: Politics and perspectives*, Berg, Oxford, p. 19-48

Thompson, D., (1963), *Arbor Low and three other prehistoric sites in Derbyshire*, Her Majesty’s Stationery Office, London

Tilley, C., (1994), ‘A Phenomology of Landscape: Places, Paths and Monuments’, Berg, Oxford

Tinkham, W. T., and Swayze, N. C., (2021), ‘Influence of Agisoft Metashape parameters on UAV Structure from Motion Individual Tree Detection from Canopy Height Models’, *Forests*, **12**, Article No. 250

Tomasi, C., and Kanade, T., (1992), ‘Shape and motion from image streams under orthography: a factorization method’, *International Journal of Computer Vision*, **9**(2), p. 137-154

Trentelman, C. K., (2009), ‘Place attachment and community attachment: A primer grounded in the lived experience of a community sociologist’, *Society of Natural Resources,* **22**, p. 191–210

Tristram, E., (1915), ‘The stone circle, known as the “Bull Ring” at Dove Holes, and the Mound adjoining’, *Deryshire Archaeological Journal*, **37**, p. 77-86

Troll, C., (1939), ‘Luftbildplan and okologische bodenforschung’, *Zeitshraft der Gesellshacft fur Erdkunde Zu Berlin*, p. 241-298

Troll, C., (1971), ‘Landscape ecology (geoecology) and biogenocenology – a terminology study’, *Geoforum*, **8**(71), p. 43-46

Tucci, G., Bonora, V., Conti, A., & Fiorini, L. (2017), ‘High-quality 3D models and their use in a cultural heritage conservation project’*, The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences,* **XLII-2/W5**, p. 687-693

Turner, W., (1903), ‘Notes on old Buxton and district’, *Derbyshire Archaeological Journal*, **25**, p. 159-163

Tveit, M., Ode, A., and Fry, G., (2006), ‘Key concepts in a framework for analysing visual landscape character’, *Landscape Research*, **31**(3), p. 229-255

Übel, M. V. (2019). Free 3D models – Best download sites & 3D archives of 2019. *Get the Best for Free.* Retrieved 12 February, 2019, from https://all3dp.com/1/free-3d-models-download-best-sites-3d-archive-3d

Ullah, I., (2011), 'A GIS method for assessing the zone of human-environmental impact around archaeological sites', *Journal of Archaeological Science*, **38**, p. 623-632

Ulrich, R.S., (1993), 'Biophilia, biophobia, and natural landscapes', *In*: Kellert, S.R., Wilson, E.O. (Eds.), *The Biophilia Hypothesis,* p. 73–137, Island Press, Washington DC,

UNESCO, (1972), 'UNESCO: Convention concerning the protection of the world cultural and natural heritage', UNECSO, Paris

UNESCO, (1976), 'Recommendation concerning the Safeguarding and Contemporary Role of Historic Areas', ONLINE, https://www.icomos.org/publications/93towns7o.pdf, accessed 7th February 2019

UNESCO, (2003), 'UNESCO Declaration concerning the Intentional Destruction of Cultural Heritage', ONLINE, http://portal.unesco.org/en/ev.php-URL_ID=17718&URL_DO=DO_TOPIC&URL_SECTION=201.html, accessed 25th July 2022

UNESCO, (2013), 'The Hangzhou Declaration ''Placing Culture at the Heart of Sustainable Development Policies"', *In*: 'Hangzhou Congress on Culture and Development', China, ONLINE, http://www.unesco.org/new/fileadmin/MULTIMEDIA/HQ/CLT/images/FinalHangzhouDeclaration20130517.pdf, accessed 21st March 2019

UNESCO, (2016), 'Global Report on Culture for Sustainable Urban Development', UNESCO, Paris, ONLINE, https://unesdoc.unesco.org/ark:/48223/pf0000245999, accessed 21st March 2019

UNESCO, (2022), 'UNESCO in brief', ONLINE, https://www.unesco.org/en/brief, accessed 25th July 2022

UNESCO-WHC (World Heritage Committee), (2005), 'Vienna Memorandum on World Heritage and Contemporary Architecture – Managing the Historic Urban Landscape', ONLINE, https://unesco.lt/uploads/file/failai_VEIKLA/kultura/RA_Vienna_memorandum.pdf, accessed 21st March 2019

Unger, J., Hemker, C., Lobinger, C., and Jan, M., (2020), ONLINE, 'VirtualArch: Making Archaeological Heritage Visible', *Internet Archaeology*, **54**, https://doi.org/10.11141/ia.54.2 - accessed 7th September 2020

United Nations, (2015), 'Transforming our world: the 2030 Agenda for Sustainable Development Summary', ONLINE, https://sustainabledevelopment.un.org/post2015/transformingourworld, accessed 5th November 2018

University of Oxford, (2023), 'Archaeology from Above', ONLINE, https://www.ox.ac.uk/research/research-impact/archaeology-above, accessed 16th Februrary 2023

Ur, J. A., (2003), 'CORONA satellite photography and ancient road networks: A Northern Mesopotamian case study', *Antiquity,* **77**(295), p. 102-115

Valle Abad, P., Fernández Fernández, A., & Rodríguez Nóvoa, A. A. (2022), 'Lost archaeological heritage: virtual reconstruction of the medieval castle of San Salvador de Todea', *Virtual Archaeology Review*, **13**(26), p. 22–44

Van Den Berg, A.E., and Koole, S.L., (2006), 'New wilderness in the Netherlands: an investigation of visual preferences for nature development landscapes', *Landscape and Urban Planning,* **78**, p. 362–372.

Vattapparamban, E., Guvenc, I., Yurekli, A. I., Akkaya, K., and Ulugac, S., (2016), 'Drones for Smart Cities: Issues in Cybersecurity, Privacy, and Public Safety', *In: 2016 International Wireless Communications and Mobile Computing Conference (IWCMC),* p. 216-221

Verhoeven, G. J. J., (2009), 'Providing an Archaeological Bird's-eye View ^ an Overall Picture of Ground-based Means to Execute Low-altitude Aerial Photography (LAAP) in Archaeology', *Archaeological Prospection*, **16**(4), p. 233-249

Vilbig, J. M., Sagan, V., and Bodine, C., (2020), 'Archaeological surveying with airborne LiDAR and UAV photogrammetry: A comparative analysis at Cahokia Mounds', *Journal of Archaeological Science: Reports*, **33**, 102509

Vincent, J. B., Werden, L. K., and Ditmer, M. A., (2015), 'Barriers to adding UAVs to the ecologist's toolbox', *Frontiers in Ecology and the Environment*, **13**(2), p. 74-75

Ward, J., (1908), 'Notes on some Derbyshire Antiquities from Samuel Mitchell's Memoranda', *Derbyshire Archaeological Journal*, **30**, p. 155-172

Weber, J., and Powis, T. G., (2014), 'Assessing Terrestrial Laser Scanning in Complex Environments: An Approach from the Ancient Maya Site of Pacbitun, Belize', *Advances in Archaeological Practice*, **2**(2), p. 123-137

Webster, D. S., (1999), 'The concept of affordance and GIS: a note on Llobera (1996)', *Antiquity*, **73**, p. 915-917

Wertheimer, M., and Kiezler, K., (1944), 'Gestalt theory', *Social Research*, p. 78-99

Westoby, M. J., Brasington, J., Glasser, N. F., Hambrey, M. J., and Reynolds, J. M., (2012), ‘Structure-from-Motion photogrammetry: A low-cost, effective tool for geoscience applications’, *Geomorphology*, **179**, p. 300-314

Weston, R., (2000), Hartington; a landscape history from the earliest times to 1800, Derbyshire County Council Libraries & Heritage Department, Derbyshire

Wheatley, D., (1996), ‘The use of GIS to understand regional variation in earlier Neolithic Wessex’, *In:* Maschner, H. D. G., (ed.), *New methods, old problems: geographic information systems in modern archaeological research*, Centre for Archaeological Investigations Occasional Paper, University of Carbondale, Southern Illinois, **23**, p. 75-103

White, S. M., Schaefer, M., Barfield, P., Cantrell, R., and Watson, G. J., (2022), ‘Cost benefit analysis of survey methods for assessing intertidal sediment disturbance: A bailt collection case study’, *Journal of Environmetal Management*, **306**, https://doi.org/10.1016/j.jenvman.2021.114386

Witcher, R. E., (1999), ‘GIS and landscapes of perception’, *In:* Geographical information systems and landscape archaeology, Oxbow Books, Oxford, p. 13-22.

Witmer, B. G., and Singer, M. J., (1998), ‘Measuring presence in virtual environments: A presence questionnaire’, *Presence: Teleoperators and Virtual Environments,* **7**(3), p. 225-240

Wood, M. J., and Pluckhahn, T. J., (2018), ‘*Terra incognita*: terrestrial LiDAR documentation of Mound A at Kolomoki (9ER1)’, *Southeastern Archaeology*, **37**, p. 95-111

Wu, J. J., (2006), ‘Landscape ecology, cross-disciplinarity, and sustainability science’, *Landscape Ecology*, **21**, p. 1-4

Wu, J., (2007), ‘Past, present and future of landscape ecology’, *Landscape Ecology*, **22**, p. 1433-1435

Xiao, W., Mills, J., Guidi, G., Rodriguez-Gonzalvez, P., Gonizzi Barsanti, S., and Gonzalez-Aguilera, D., (2018), ‘Geoinformatics for the conservation and promotion of cultural heritage in support of the UN Sustainable Developments Goals,’ *ISPRS Journal of Photogrammetry and Remote Sensing*, **142**, p. 389-406

Yim, J. and Graham, T.N., (2007), ‘Using games to increase exercise motivation’, *Proceedings of the 2007 conference on Future Play*, p. 166-173

Yu, K., (1995), ‘Cultural variations in landscape preference: comparisons among Chinese sub-groups and Western design experts’, *Landscape and Urban Planning,* **32**, p. 107–126.

Zaksek, K., Ositr, K., and Kokalj, Z., (2011), ‘Sky-view factor as a Relief Visualization Technique’, *Remote Sensing*, **3**, p. 398-415

Zhang, C., and Kovacs, J. M., (2012), ‘The application of small unmanned aerial system for precision, Drones and Aerial Observation: New Technologies for property rights, human rights, and global development a primer agriculture: a review’, *Precision Agriculture*, **13**, p. 693-712

Zhou, W., Chen, F., Guo, H., Hu, M., Li, Q., and Tang, P., (2020), ‘UAV Laser scanning technology: a potential cost-effective tool for micro-topography detection over wooded areas for archaeological propsection’, *International Journal of Digital Earth*, **13**(11), p. 1279-1301

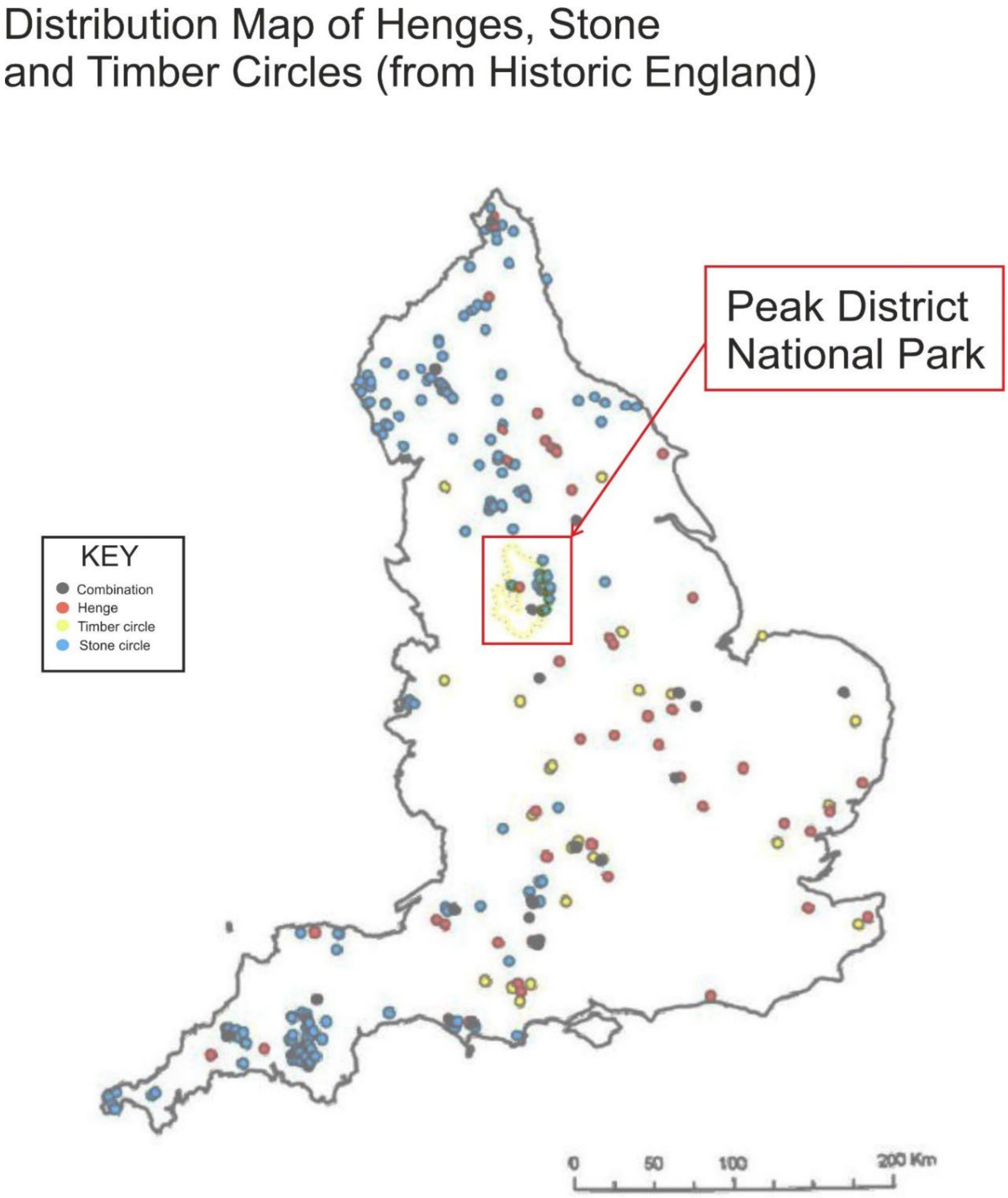
Zube, E.H., Pitt, D.G., Evans, G.W., (1983), ‘A lifespan developmental study of landscape assessment’, *Journal of Environmental Psychology*, **3**, p. 115–128

Zubrow, E. B. W., (1990), ‘The fantasies of GIS software’, *In:* Allen, K. M.S., Green, S. W., and Zubrow, E. B. W., (eds.), *Interpreting Space: GIS and Archaeology*, Taylor & Francis, London

Zyda, M., (2005), ‘From visual simulation to virtual reality to games’, *Computer*, **38**(9), p. 25–32

Appendix A: Distribution Map of Henges, Stone and Timber Circles

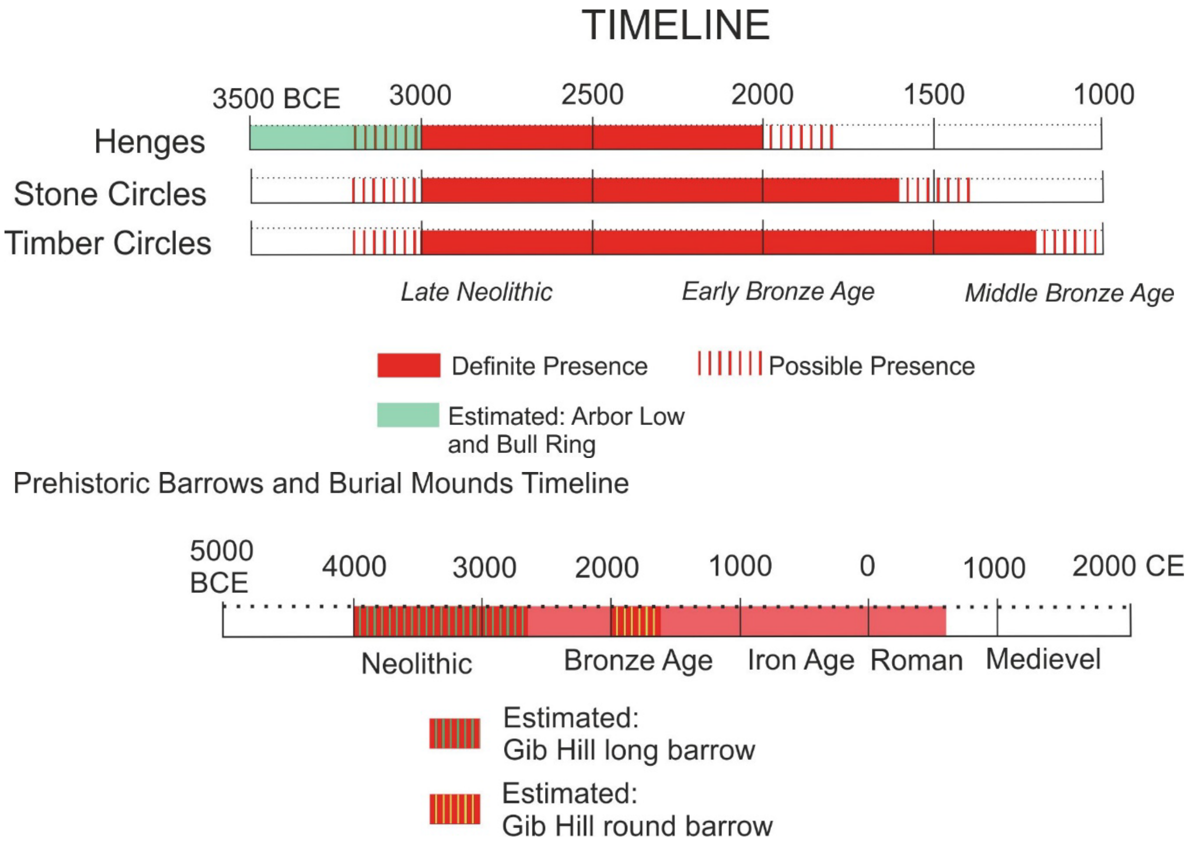
Historic England (2018b) created this map as part of their series on heritage assets in the UK, and it was adapted by the author of this PhD to highlight where the Peak District National Park is situated in the context of this asset. As it shows, stone circles are clearly marked on this map (blue dots) on the western edge of the national park (yellow line), and Arbor Low is dotted in red, but not Bull Ring.



Appendix A: A distribution map of the types of henges and stone/timber circles, depicting the PDNPA (pale yellow line/red box). Adapted from Historic England (2018b).

Appendix B: Timeline of Henge, Stone and Timber Circles & Timeline of Barrows

Again, adapted from Historic England (2018b), these timelines are marked additionally with ages of the monuments investigated in this PhD, namely Arbor Low, Bull Ring, and the two barrows at Gib Hill, using dates theorised by researchers. This was created by using the estimated ages proffered by McGuire and Smith (2008) for Gib Hill barrows and Arbor Low, and because the Bull Ring and Arbor Low are compared, this same age was used for Bull Ring as well.

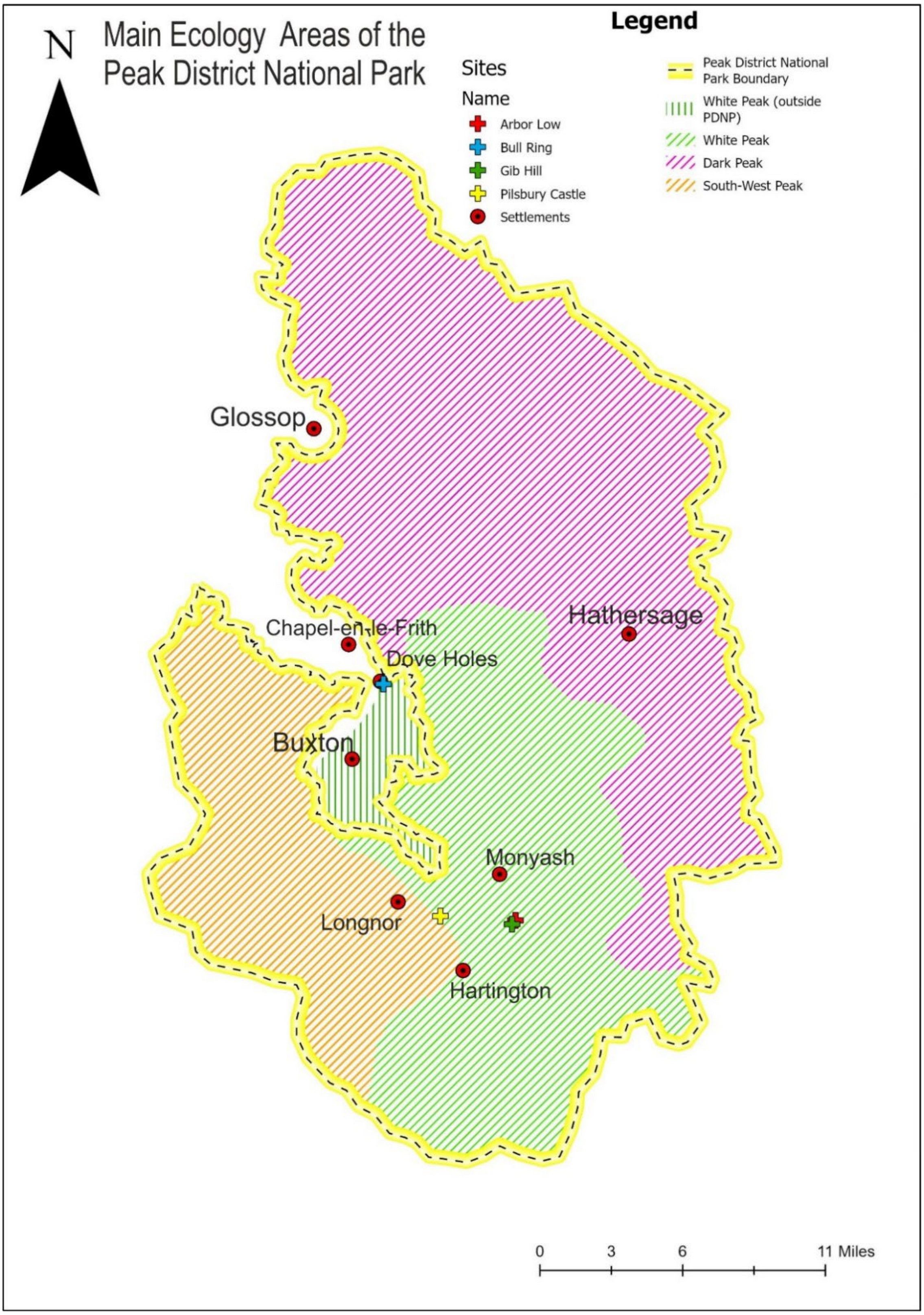


Appendix B: These timelines, adapted from Historic England (2018b) have the dates of three of the sites of investigation highlighted to show where they fall within current knowledge of these monument types.

Appendix C: Three Main Regions of the Peak District National Park Map

This map was created using individual maps made by the PDNPA (2020c; 2020d; 2020f) and merged together to give a complete, but comparatively simplistic overview of the regions of the park.

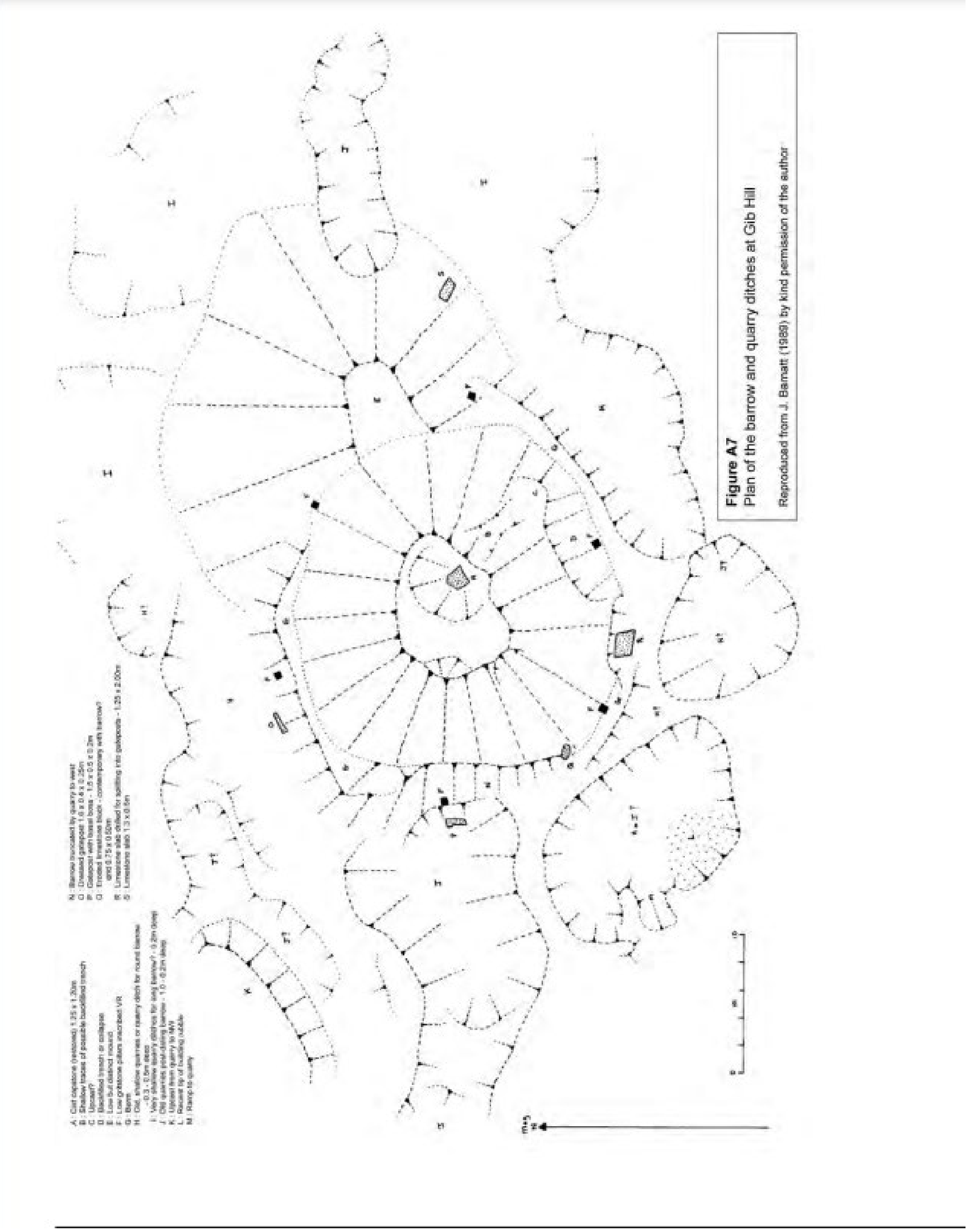
This is commonly how the park is divided, as explained in Chapter 3, but there are more than these three areas, such as the southern valleys and the shale valleys that are present and named separately when in depth discussion is had about the park. For the general public, however, this is how it is presented.



Appendix C: Combining three single maps by the PDNPA, as explained above (PDNPA 2020c; 2020d; 2020f), the main divisions of the national park.

Appendix D: Gib Hill Survey

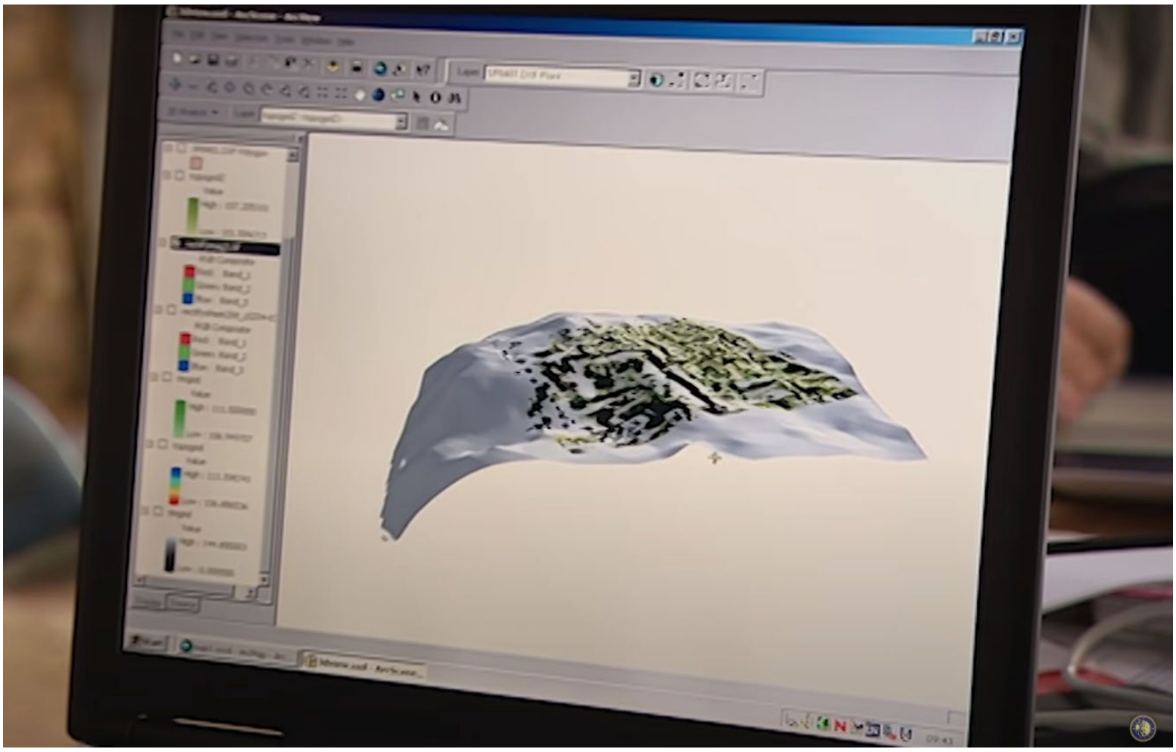
This Gib Hill survey was completed by Barnatt, possibly from his *Peak Barrow Survey* in 1989, but the image was found in McGuire and Smith (2008). It was used in the analysis of Gib Hill to clearly establish where shapefiles needed to be drawn in order to reconstruct the barrows. It was also used to identify the pits and their depths, as they differed by pit type, as discussed in Chapter 4.



Appendix D: Likely from Barnatt (1989b)'s round barrow survey, but found in McGuire and Smith, (2008), this aided in determining where aspects of the barrows lay.

Appendix E: ArcGIS in Time Team

As was explained in Chapter 2, GIS software, such as ArcGIS, has been used by experts in archaeology. Here is an image of the use of GIS in the well known television programme, Time Team. In the episode '*Bodies in the Shed'* (2006), a DEM and geopysichal imaging data as been imported into the software to understand the lay of the land alongside the gathered data. This is how it has been used by Time Team here, and by other researchers. The intent of this PhD research was to go one step further by utilising data present at the site and researchers' theorised measurements alongside each other for comparison and rebuilding inside GIS software, something different to what is being demonstrated in this image.



Appendix E: the popular TV documentary show used ArcGIS in many episodes as part of their excavations.

Appendix F: Orthomosaic Imagery in 3D

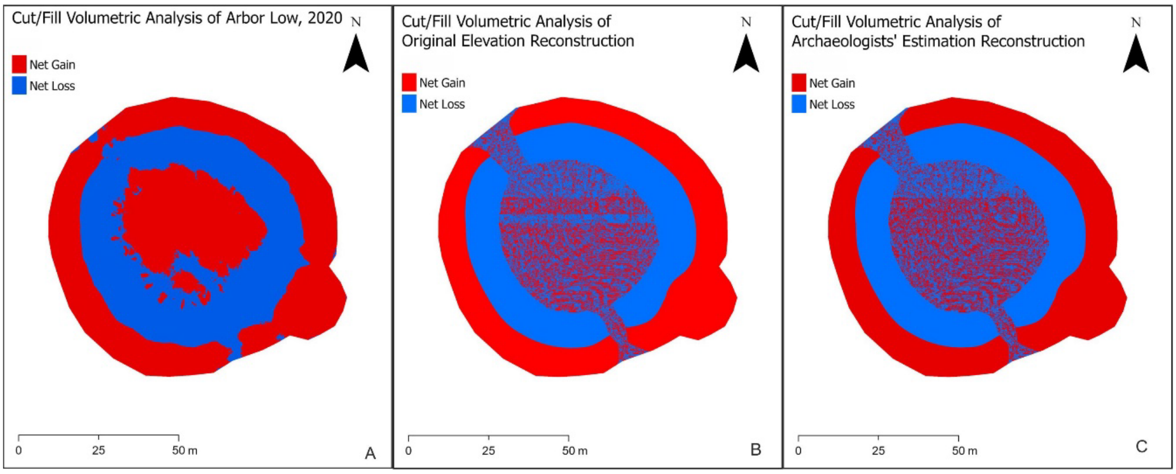
These images are best viewed in place as either images or inside GIS software in order to view these as would be intended as digital heritage, using the DEMs of the rebuilds and the contemporary orthomosaic, to better present the hypothetical monument in the way that would best utilise the information. There are also short videos that move around the sites, as well as the files required to view them in GIS software.

Appendix G: Contemporary Relative Height DEMs and Modelled Topographies

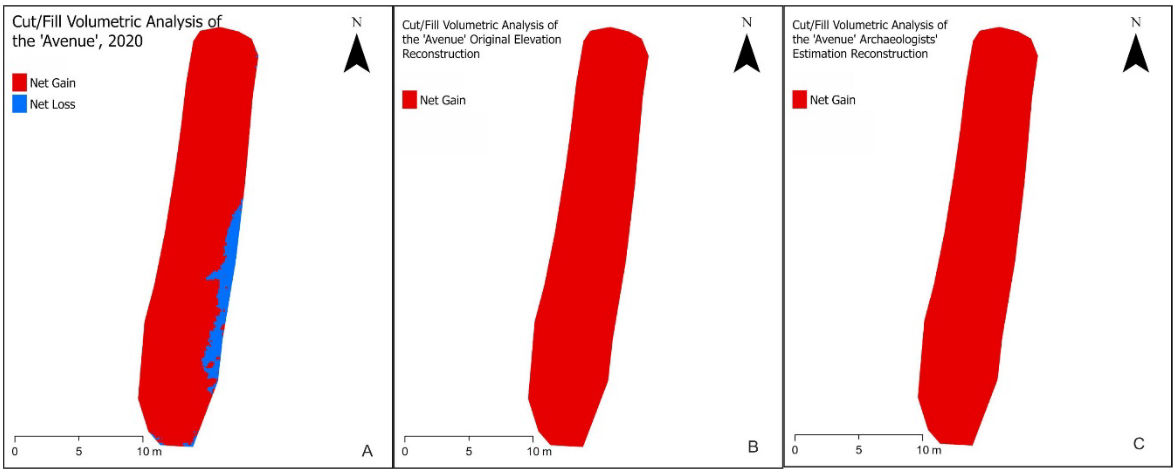
These images are best viewed in place as either images or inside GIS software in order to more easily understand what these DEMs looked like in the analysis view, and when used with orthomosaic imagery, understand the how the modelled topography appears without the heritage monument present. This appendix is included separately to the thesis.

Appendix H: Cut Fills of the Sites (Visualisations)

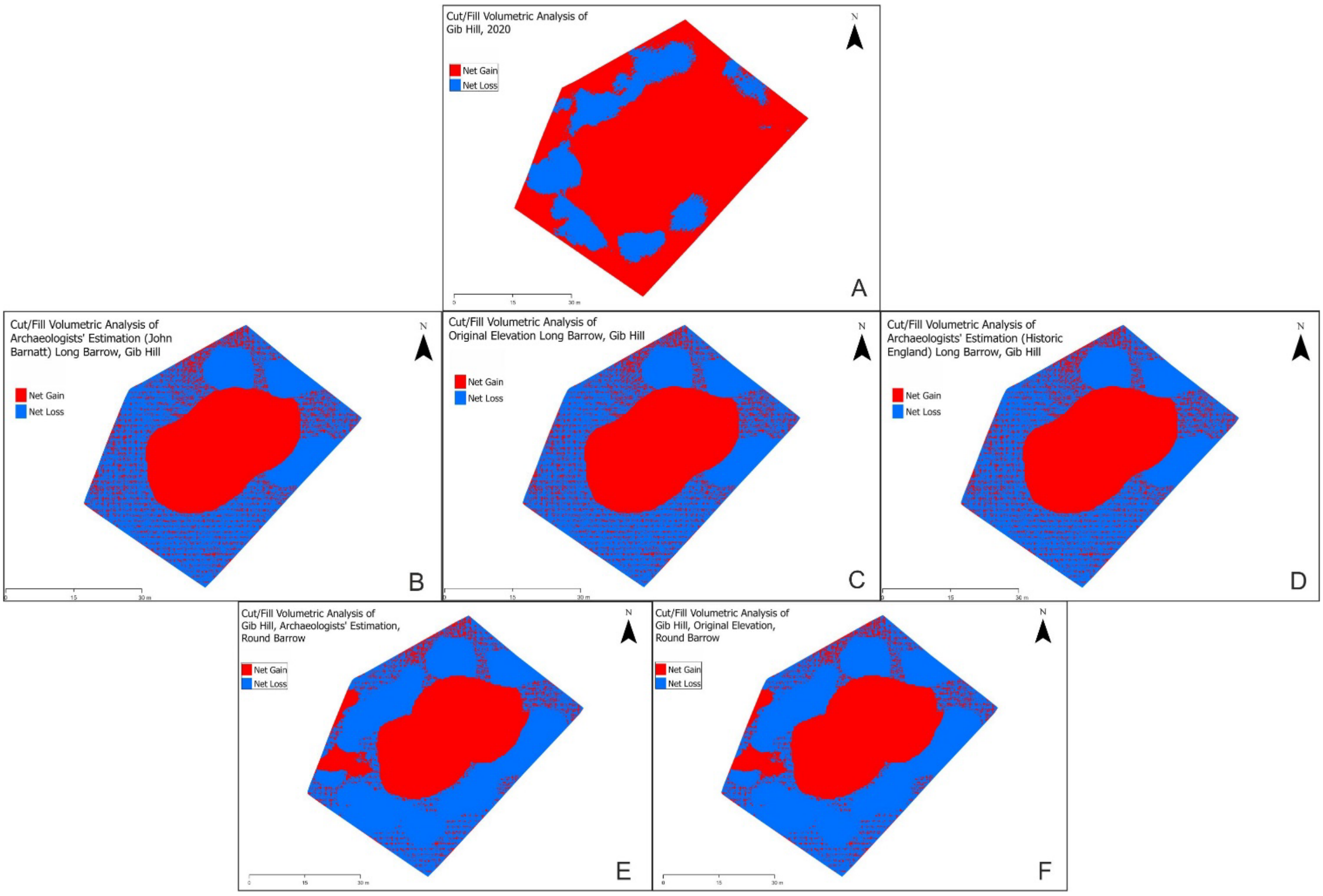
In Chapter 5, the results of volumetric analysis of contemporary and reconstructions of each site were together in tables, one for each monument. The *cut/fill* tool, as explained in Chapter 4, the difference is calculated between two surfaces, in this case the Modelled Topography (MT) and the DEMs of each site, contemporary and hypothetical reconstructions. The outputs were visualised as Net Gain or Net Less automatically from the *cut/fill* action, and there are no defined numbers given to any select area, thus these visualisations are not overly useful as in some there is only gain, such as the Avenue, however, they are included. Firstly, is Arbor Low and the Avenue, then followed Gib Hill, Bull Ring and Pilsbury.



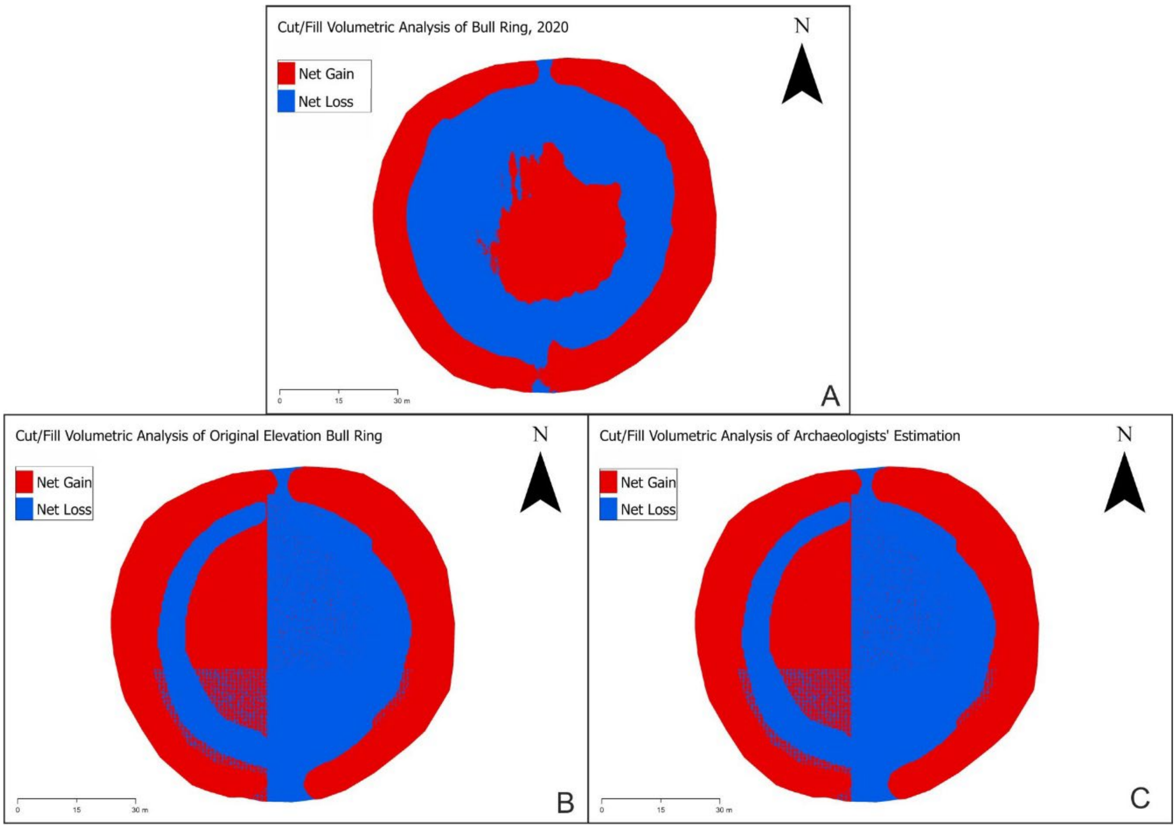
Appendix H1: The visualisations of Arbor Low's different cut/fill volumetric analyses.



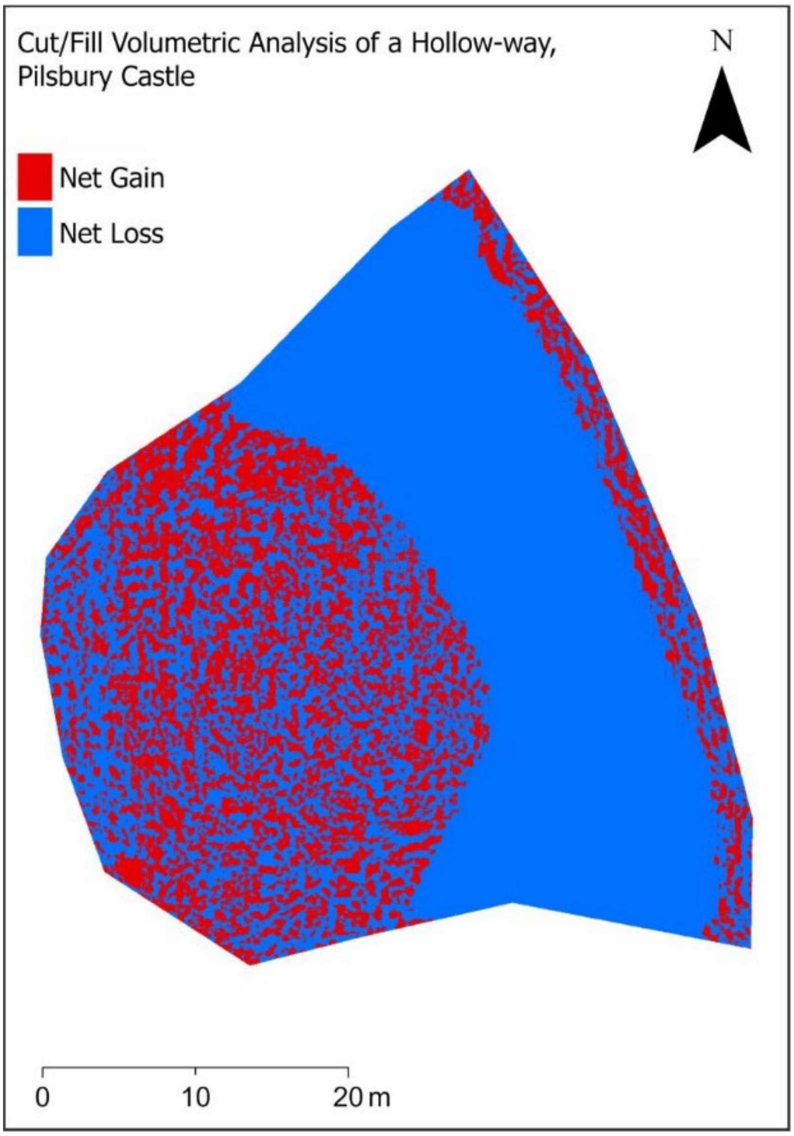
Appendix H2: Visualisations of Avenue cut/fills volumetric analyses



Appendix H3: Due to the number of rebuilds, there were several volumetric analysis visualisations



Appendix H4: The damage at the Bull Ring may explain why there is such clear divisions in these visualisations of volume analysis.



Appendix H5: There is a 'loss' here, because this volume analysis was between the modern day hollow-way and the filled in hollow-way of the past, if indeed it ever was prior to construction

Appendix I: Inside the Minecraft Server for Ruins Reimagined: Corfe Castle via the National Trust (2022)

Recently, the National Trust, historians and gamers came together to create a reimagined Corfe Castle in the popular game *Minecraft* (National Trust, 2022). A historian's knowledge guided an expert gamer in rebuilding Corfe Castle and its different architecture from across its long history. This is what game and gaming can offer to encourage interest and be used not just for recreation, but education.

Appendix I: An example of gaming and history coming together in *Minecraft*, where information has been used to rebuild Corfe Castle, its varied additions over time and its landscape in a platform millions use.

Appendix J: ACiD Magazine Article (2022)

In January 2022, the author was invited to write a short piece on this PhD work in the ACiD magazine, where it featured in the magazine of that year, across three pages, outlining the intent and brief explanation of what was being done as part of the research and how it would be helpful. The link to the magazine will be part of the Appendices files included with this thesis.

Picturing the past

Pilsbury Castle Hills

This aerial image shows the dramatic motte and bailey of Pilsbury Castle Hills. It is unusual in having three outer baileys (fortified outer enclosures) rather than one. This is one of many images that is being used by researchers at Keele University to test the use of drone photography and 3D digital models in for mapping and monitoring erosion at heritage sites. (See feature on p18)

FSC
www.fsc.org
MIX
Paper from responsible sources
FSC® C002375

DERBYSHIRE County Council

PEAK DISTRICT NATIONAL PARK

Monitoring heritage sites · from the air

Aerial photograph from February 2020 clearly showing the main 'desire lines', or routes people take, when visiting Arbor Low. Hundreds of aerial images are combined to generate a 3D digital model

A photorealistic 3D model of Gib Hill. It has been processed using Structure-from-Motion (SfM) which tracks features over many hundreds of aerial images and aligns them to create a 3D model. Here, soil erosion on the barrow sides is identified in the purple areas and can be measured very accurately

HELEN MALBON describes how aerial technology is shedding new light on sensitive archaeological sites

My Physical Geography PhD research at Keele University has been focused on using drones (unmanned aerial vehicles) at four earthwork heritage sites in the Peak District: Arbor Low, Gib Hill, Pilsbury Castle Hills (see Picturing the Past, p36) and Bull Ring at Dove Holes. The aim of the research was to demonstrate that aerial imagery alone can be used in low vegetation areas, such as open moorland, to document heritage landscapes and features to aid monitoring and preservation.

This was done by creating photorealistic 3D models and Digital Elevation Models (DEMs). These were imported into a Geographic Information System (GIS) to identify and visualise areas of damage or concern, providing highly useful information for organisations such as the Peak District National Park Authority and Derbyshire County Council.

The resulting images can have incredibly high resolution of around 3-4 cm – better than that which is available online as downloadable datasets. All this can be achieved by using a widely available medium-sized drone, without having to use more expensive techniques such as LiDAR. The monitoring can be done as often as needed in order to supplement other surveys of heritage features or landscapes in order to inform their conservation. The 3D models mean that a long-lasting digital archive record of each site has also been made.

An additional aim of the research was to attempt hypothetical reconstructions of the monuments, to imagine how they may have appeared when first built, using both contemporary data and archaeologists' estimations. This part of the research is still being completed. The resulting images and 3D models – of existing features or hypothetical reconstruction – could be used in public outreach and education on various platforms, and also provide access to individuals who cannot physically visit the sites.

18 ACID | 2022

2022 | ACID 19