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A Cost-Effective Approach to Monitoring Outdoor Heritage Sites

Eleanor Evans[1]

[1]*PhD Student, Centre for National Parks & Protected Areas, University of Cumbria, UK.*

Abstract

This research aimed to design and critically evaluate a novel method to monitor visitor behaviour and the physical condition of outdoor heritage sites and monuments in Cumbria. The method used aerial photography and photogrammetry to repeatedly record the physical condition of selected free-to-enter Cumbrian heritage sites over a six-month period, whilst visitors' routes around these chosen sites were also recorded. This allowed conclusions to be drawn about visitor impact, vulnerable points on site, areas of high foot-traffic, and the impact of climatic conditions on the heritage sites. A key outcome of the research and fieldwork was the design of a new cost-effective toolkit to assist heritage organisations in assessing loss of heritage assets (such as physical deterioration) at their sites.

Keywords

Heritage site; Photogrammetry; Visitor studies; Toolkit development; PHD research

1. Introduction

1.1. Types of Heritage

There are numerous types of heritage, including natural and cultural heritage (UNESCO, 2021a). Natural heritage refers to heritage assets that were created by biological and/or physical processes (UNESCO, 2021b). An example of a natural heritage site is the Giant's Causeway and Causeway Coast in Northern Ireland (UNESCO, 2021a). Cultural heritage encompasses human-made intangible and tangible heritage assets (UNESCO, 2003), such as traditions, languages, oral histories, rituals, manufactured objects, technologies, buildings, and structures. Tangible heritage assets are those that can be physically interacted with, for example, archaeological artefacts, buildings, and clothing (UNESCO, 2021b). Heritage tourism is often driven by the presence of tangible heritage assets as a physical place or item which people can visit and see as part of a trip. Intangible heritage assets are not physical entities but exist in cultural practices and memory. Folklore, languages, dances, beliefs, and cooking techniques are all examples of intangible heritage (UNESCO, 2003). Intangible heritage can be directly associated with tangible heritage assets or can exist independently.

Heritage is important because it provides history and context for communities to form an identity around, as well as being valuable for telling stories of the past and how societies have evolved over time (Heritage Council, 2021). Protective measures can help to ensure that heritage assets and cultural memory are not lost. For example, in the UK, National Landscapes are areas of environmental and natural significance which are legally protected to preserve them against loss of heritage and natural assets (National Landscapes, 2024). Heritage organisations worldwide can access the United Nations Educational, Scientific and Cultural Organisation ('UNESCO') Convention for the Safeguarding of the Intangible Cultural Heritage to source information to assist them in preserving intangible heritage assets (UNESCO, 2003).

1.2. Heritage Sites and Cultural Landscapes

In 2019, the heritage sector in England contributed £31 billion to the UK economy (Historic England, 2019). Heritage Visitor Attractions (‘HVAs’) are a key part of the visitor economy, including museums, heritage sites with admission fees, and free-to-enter heritage sites (Millar, 2009) (Department for Digital, Culture, Media & Sport, 2017). Free-to-enter outdoor heritage sites are a type of HVA that are often visited by people for recreation and education (Millar, 2009).

Ancient and scheduled monuments have been preserved for the appreciation and enjoyment of people today and for future generations (Historic England, 2021a). They make up and add value to the Historic Environment. The Historic Environment includes all areas of an environment changed or influenced by humans (Historic England, 2021a).

Monuments are physically built structures or areas located on a site contributing to its meaning and history (Marschall, 2010). Heritage sites are areas of land that hold significance because of their past use. Monuments can be located inside a heritage site, and heritage sites are set within a cultural and/or historic landscape (Historic England, 2021a). Some outdoor heritage sites have visitor centres with staff and volunteers to assist visitors. There are also outdoor heritage sites which do not have these facilities and are free-to-enter by visitors. Without a permanent staff and volunteer presence, these sites are less likely to have frequent condition, livestock, visitor, weather, and wildlife monitoring programmes. The owners and managers of these sites may have limited time and financial resources to monitor them, as their focus is generally on primary income streams. For example, some heritage sites can be located within farmland where farming activities are the main economic focus of the site.

1.3. Threats to Outdoor Heritage Sites

Outdoor heritage sites are exposed to a range of threats, including damage by livestock, visitors, weather conditions (including extreme weather events), and wildlife. It is not always practicable to shield a site from these threats.

The raising of livestock is important to provide food supplies, produce materials, and generate income, but grazing animals can cause damage to the cultural and historic landscape (Historic England, 2023). Livestock can cause soil erosion, ground poaching, and erosion scars in the ground. A document published by Historic England in 2023 provides guidance for livestock management when animals are grazing on archaeological sites with an aim to reduce the development of erosion scars and ground poaching from hooves (Historic England, 2023). Grazing livestock contributes to cultural heritage and historic land use practices, and in some areas around the world, farming practices such as these are protected. In the UK, many free-to-enter outdoor heritage sites provide grazing sites for livestock; for example, cows graze within the site of Long Meg and Her Daughters Stone Circle for part of the year.

Visitor presence at heritage sites also brings threats. Erosion of footpaths around heritage sites can be caused by visitor footfall (Rodway-Dyer & Ellis, 2018). Monuments and features can be focal points for visitors and can result in areas of high footfall around the base of these structures, which can lead to concentrated soil erosion. Visitors can also disrupt agricultural industries in the area with the potential of damaging crops, spooking livestock, and blocking access routes with their vehicles whilst visiting a heritage site (Young, 1999). Another threat to heritage sites is vandalism by visitors. Writing or carving into surfaces, theft of historic material, and damaging works are all forms of vandalism (Qwatekana et al., 2021). English Heritage has published a guidance document looking into the consequences of increasing visitor numbers at heritage sites, which includes studying the loss of heritage assets and erosion (English Heritage, 2024).

Extreme weather events can lead to increased deterioration at outdoor heritage sites. Wildfires, flooding, and hurricanes have all caused permanent loss of heritage assets at sites around the world. Flooding can cause irreversible structural damage and losses of heritage assets. English Heritage has published a report listing several of its heritage sites that are at high risk of flooding, to enable them to address this issue (Pearson, 2013).

Wild animals and plant life at outdoor heritage sites can cause deterioration of heritage assets. Microorganisms such as lichen are often found growing on stone heritage structures, and can cause chemical and mechanical erosion to stone surfaces (Inkpen & May, 2006). Other examples of common microorganisms found at heritage sites are algae, actinomycetes, cyanobacteria, and fungi. Moss can be found growing on stone surfaces, which may cause discolouration.

In summary, there is a wide range of threats to heritage sites, and it is not always possible to eliminate exposure to them. Deterioration of outdoor heritage assets cannot be eliminated; however, it can be slowed down. A cost-effective toolkit could be implemented to inform the development of heritage management strategies, which can be put in place to prolong the existence of heritage assets, including sites.

1.4. Heritage Management

Heritage management strategies involve a range of approaches, including regulation and manipulative controls, to reduce the impact of threats to heritage sites.

A key part of heritage site management is understanding the site's carrying capacity. Carrying capacity is an evaluation of how much pressure, for example, by visitors, can be put on a site without its assets being damaged or destroyed (Mansfield, 2018). It is a constant balance that needs to be found between the conservation needs of a site and the needs and demands of visitors (**Figure 1**). To avoid reaching a point where a site has exceeded its carrying capacity, management strategies need to be implemented by site managers.

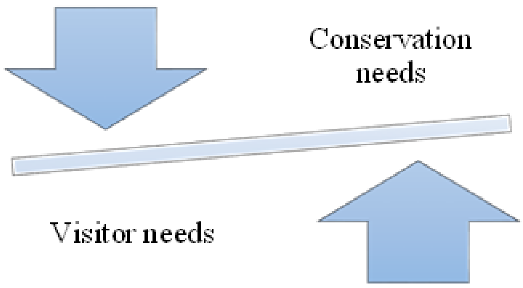


Figure 1. Push-pull diagram of conservation needs and visitor needs.

UK Heritage sites are managed by a number of bodies at different levels, including the UK Government Department for Digital, Culture, Media and Sport ('DCMS') (which oversees the Listing of buildings and Scheduling of monuments) (Department for Digital, Culture, Media and Sport, 2013), Historic England, societies and specialist advisory groups, heritage asset owners and site managers such as English Heritage and the National Trust, as well as private land owners. International stakeholders may also be involved in the management of heritage sites, including the International Council on Monuments and Sites ('ICOMOS') (ICOMOS, 2025) and UNESCO (UNESCO, 2025).

UNESCO designates certain sites as World Heritage Sites ('WHS') on an international scale. To meet the criteria to become a WHS, a site must prove its 'Outstanding Universal Value' (UNESCO, 2021b). Once WHS status is achieved, the site must be protected and maintained under the World Heritage Convention 1972, which is a legal framework to help safeguard heritage sites (UNESCO, 2021c). On a national level, the DCMS creates policies and guidelines for the protection of heritage assets such as monuments (Department for Digital, Culture, Media and Sport, 2013) and the UK Parliament makes laws to protect heritage assets from damage and destruction (Historic England, 2021b).

Managers of heritage sites can implement regulatory controls, such as admission fees, opening hours, restricted routes, and site closure on certain dates and times. However, it is often difficult to put these controls in place at free-to-enter sites, many of which are not staffed. This is why legal guidelines for the protection of heritage sites and monuments are vital for their preservation. The DCMS published a paper outlining the need to monitor the loss of heritage assets (Sagger et al., 2021).

Free-to-enter sites often implement manipulative controls to encourage visitors to act a certain way without the presence of staff or volunteers (Mitchell, 1979). Visitor flows are the routes frequently taken by people through a site and can be recorded by observing how people behave (Beritelli et al., 2020). Once a heritage site's visitor flows have been identified, manipulative controls can be put in place to encourage shifts in the visitor flow to reduce the risk of further damage (Cvelbar et al., 2018).

An example of manipulative controls is the positioning of interpretation panels at certain parts of a site to encourage people to visit them, rather than other, more vulnerable areas of the site (Mitchell, 1979). Interpretation panels are commonly used for presenting contextual information about a heritage site to the public, and can also influence their chosen route around a site. These controls are particularly useful when there is no permanent staff or volunteer presence on site. Free-to-enter outdoor heritage sites have less frequent monitoring and less staff and volunteer presence. These were therefore identified as sites that would benefit from more frequent monitoring to help inform future site management decisions. A cost-effective method to monitor sites that is accessible for beginners and provides clear results would be beneficial to small heritage organisations, particularly those that are volunteer-led. The results of such monitoring should help to inform future decisions in the choice of heritage management strategies to implement at sites.

2. Aims & Objectives

2.1. Aim

The PhD research aimed to design a method for recording the physical condition and visitor routes at five selected free-to-enter Cumbrian outdoor heritage sites. Then, to develop a toolkit based on the resulting method.

2.2. Objectives

The research objectives were firstly to write a literature review and evaluation of existing research to inform the design of the methodology. Next, a number of sites were selected for the research based on chosen criteria, and then a method for monitoring the selected sites was devised. Once the method was designed, surveys were carried out at least four times at each site, then the results were processed, interpreted, and compared. Finally, vulnerable areas at the sites were identified, suggestions for conservation strategies were made for each site, and the toolkit was designed.

3. Methodology

3.1 Site Selection

A suite of criteria was used to assess the suitability of sites for study. These included access to the site, presence of a monument on site, proximity to roads and parking areas, type of regulatory and manipulative controls, type of site, site ownership, and management. It was also important to gather data about different types of heritage sites, so a range of site types were considered for selection. To create a comparative study, some sites were located inside the English Lake District UNESCO WHS and National Park (Lake District National Park, 2022), whilst others were outside the boundary. All the selected sites were located in Cumbria, in northwest England.

A vital stage in confirming the selected sites was gaining permissions from site owners and managers. After the selection process was complete, Ambleside Roman Fort, Castlerigg Stone Circle, Kendal Castle, Long Meg and Her Daughters Stone Circle ('Long Meg' hereafter), and Shap Abbey were selected for the study (**Figure 2**). These five sites contain different types of monuments from a range of time periods, and the size, ownership type, and topography of each site vary. Within the selection are two stone circles, which have different ownership and management types and vary vastly in size.

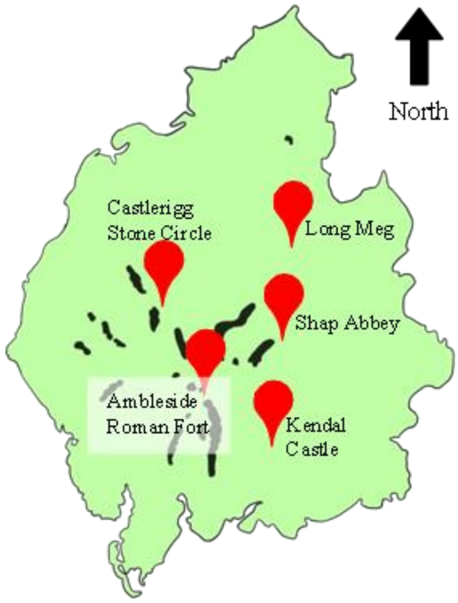


Figure 2. Map of Cumbria showing the location of selected sites in red.

3.2. Site Condition Recording

Numerous site surveying techniques were reviewed, including terrestrial photography, camera traps, video surveillance, aerial LiDAR scanning, aerial photogrammetry (see glossary), and using satellite imagery. The most cost-effective method from those reviewed was aerial photogrammetry using an Unmanned Aerial Vehicle ('UAV'), which could capture details of the ground surface and changes to the site, whilst being relatively low cost for the quality of the results achieved.

To be able to survey the sites, an aerial photogrammetry method was chosen (Historic England, 2017), so that the area could be assessed by producing 3D models of the site through photography. Aerial photographs were captured using a UAV with an integrated 'red, green, and blue' ('RGB') camera. A UAV weighing less than 250 grams was used, as this is within the Open Category (Class A1) of UAV, as designated on the Civil Aviation Authority website (Civil Aviation Authority, 2025). This type of UAV was chosen to make the aerial surveys accessible to first-time UAV pilots, and for them to have the confidence to carry out the survey using low-cost and lightweight UAVs. Permission to use the five sites and to fly a UAV over them was granted by the landowners and site managers. A Research Ethics application was approved by the University of Cumbria's Ethics Panel. Risk Assessments were carried out and approved in advance of the commencement of the fieldwork.

To capture the correct set of aerial photographs to produce a 3D model, Dronelink (Dronelink LLC, 2024) was used to design overlapping grid patterns (**Figure 3A-B**) and flight paths for the UAV. The flight path ensured photographs would have overlap (forward 80% and side 70%) (Bhambri, 2016) so that the photogrammetry software, Metashape Standard (Agisoft, 2025), could align the photographs to assist it in stitching them together to produce a resulting 3D model. **Figure 3B** shows how overlapping photographs are taken to be used to generate a 3D model. The flights also included taking photographs with different camera angles, -90° (vertical) and -70° (oblique), in order to capture details of taller parts of the monument on site (Historic England, 2017).

The altitude of the flight impacted the detail which could be collected through the aerial photography (known as the 'Ground Sampling Distance') and affected the flight time (Pix4D, 2025; Historic England, 2017). It was important to consider flight time, as the small UAV only had approximately 30 minutes of battery life and would sometimes need to be used for two flights in one day (Historic England, 2017). A lower altitude of flight would gather more detailed photographs; however, this would take longer than a higher altitude flight, as it would require more photographs (Pix4D, 2025). Testing was carried out to determine the best altitude for each site.

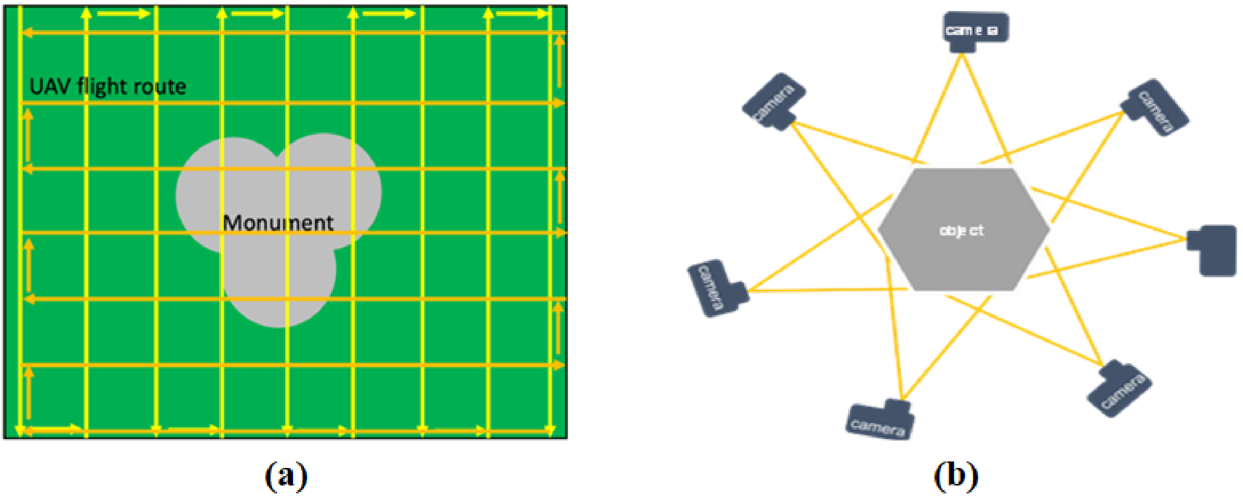


Figure 3. (a) Grid-style flight route for a UAV used to gather photographs for photogrammetry. (b) Diagram illustrating the theory of photogrammetry, showing how overlapping images are used to collect data.

Some monuments were large and in more topographically complex settings, so only certain sections of these sites were surveyed with the UAV. These sites were Kendal Castle, Long Meg, and Shap Abbey. If the project were to be carried out again, with the experience in UAV piloting gained through this fieldwork, it would be possible and preferable to survey the entire sites.

Aerial surveys were carried out multiple times at each site, with the aim of them being once a month for six months of the year. However, weather conditions sometimes prevented UAV flights from taking place, so flights had to be rescheduled for a date with dry conditions. The repeated process of collecting photographs over time allowed multiple 3D models of each site to be made, which could then be compared to one another to identify areas of physical change and interesting features on the site that may not be visible from ground level.

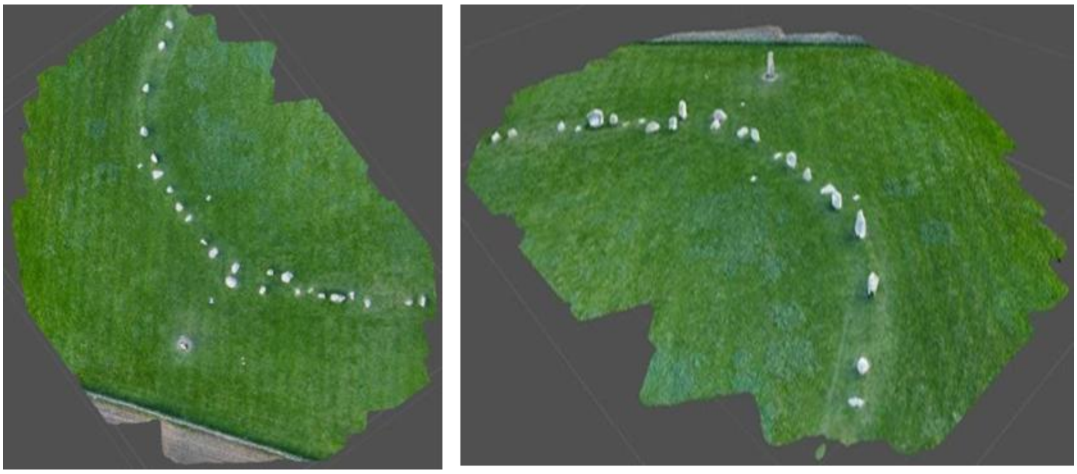


Figure 4. Aerial view of 3D model (Metashape Standard) of part of the Long Meg site from 7th April 2023.
Source. Agisoft (2025)

The aerial photographs were transferred from the SD card in the UAV to a computer, where they were each saved into a folder named after the date of the photography. The images were then uploaded into Metashape Standard (Agisoft, 2025), and then multiple stages (alignment of the photographs, building the dense cloud, building the mesh, and building the texture of the 3D model) of processing were completed to create a digital 3D model. The resulting model was saved in the dated folder, and then the point cloud (the individual points that form the basis of a digital 3D model) was exported for use later in CloudCompare (CloudCompare, 2025). This process was repeated for every aerial survey that took place, generating multiple 3D models of each site. **Figure 4** shows an example of a 3D model generated of part of the Long Meg heritage site, focusing on the tall standing stone pictured in **Figure 5a.**

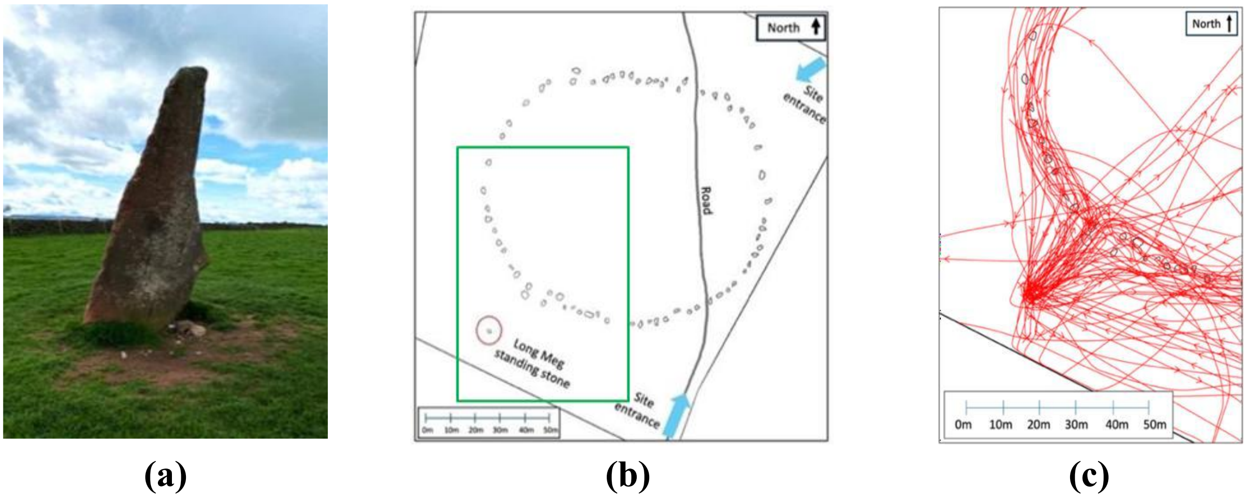


Figure 5. a) The tall standing stone at Long Meg. B) Map of the Long Meg site showing the tall standing stone circled in red, with the area of the map shown in (c) outlined in a green rectangle. C) Digitised visitor route map at Long Meg.

3.3. Visitor Route & Number Recording

A range of methods for recording visitor numbers and visitor routes at sites was considered. Using a Global Positioning System ('GPS') in conjunction with 3D models of a site could have been a useful method, but the GPS devices were costly (Zubiaga et al., 2019). Alternatively, photographs that had been geo-tagged for social media to locate spots that had been visited by people could have been used (Miyasaka et al., 2018). Another possible method involved visiting sites with a group and observing their behaviour in-situ (Roura, 2011). Infrared monitors and/or camera traps could have been used to count visitors, but these only cover certain points in a site, rather than gathering route data, and these pieces of equipment need to be regularly checked and maintained, including checking the batteries (Pettebone et al., 2010; Lupp et al., 2021).

After reviewing possible different ways of recording visitor routes and numbers, the methods chosen for this research were those that used low-cost equipment and techniques that were easy to learn. This approach was used so that staff and volunteers could carry out the surveys with minimal training time and negligible equipment costs. These factors are valuable to heritage organisations with limited budgets. The chosen method was based on the paper-and-pencil method (Yalowitz & Bronnenkant, 2009) and tally counting (Harnik & Kimball, 2004), taking place in situ on site (Roura, 2011).

Visitors were counted using a handheld click counter (Harnik & Kimball, 2004), and their routes were recorded on site during set time periods. These time periods varied from morning to afternoon and took place on significant dates of the year, such as the Summer Solstice (21st June) and Beltane (1st May), and during school holidays as well as term time. As far as practicable, recording of visitor numbers and routes at the sites took place over 6 months. Visitor routes were recorded using paper maps and drawing on the route taken by a visitor in pencil. The visitor route lines were then digitised by scanning them and tracing the image using Illustrator (Adobe, 2025), so that they could be compiled and analysed.

The data gained from recording visitor routes helped to determine areas of high foot-traffic on sites and popular times and dates of visits to the sites. By digitising the data, the routes could be overlaid onto the 3D models produced by the site surveys (Zubiaga et al., 2019). This allowed for robust conclusions to be made about the impact of visitor routes on the physical sites.

Examples of the data collected are shown in **Figures 5b** and **5c**. **Figure 5b** shows a map of the site of Long Meg, with the tall standing stone (**Figure 5a**) circled in red. This tall standing stone stands outside the main stone circle structure and has circular carvings on its surface. It is seen as a focal point at the site. **Figure 5c** shows the visitor routes overlaid onto a section of the map of the site, covering the area surveyed with the aerial photogrammetry.

In addition to the recorded visitor routes, visitor numbers were recorded at each site along with notes on the weather conditions and significant dates, such as the Summer Solstice (21st June) or Beltane (1st May). **Table 1** presents the other data collected at Long Meg related to visitor numbers.

Table 1. Visitor Numbers at Long Meg.

Date	Visitor Numbers	Length of Time (hours)	Time of day (24h clock)	Average visitors per hour	Weather conditions
02/01/2023	14	1	12:15-13:15	14	Sunny
03/04/2023	4	0.33	12:30-12:50	12	Sunny
07/04/2023	3	1.5	17:30-19:00	2	Sunny
01/05/2023 (Beltane)	10	1	15:00-16:00	10	Intermittent rain
01/06/2023	28	1.5	13:00-14:30	19	Cloudy
21/06/2023 (Summer Solstice)	26	1	13:20-14:20	26	Sunny and breezy
26/07/2023	16	1.5	12:45-14:15	11	Sunny
11/08/2023	17	0.5	16:00-16:30	34	Cloudy and dry
23/08/2023	1	1.25	15:15-16:30	<1	Sunny
24/09/2023	12	0.5	14:15-14:45	24	Raining

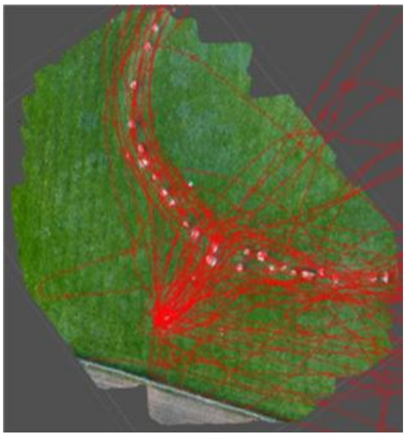
3.4. Analysis

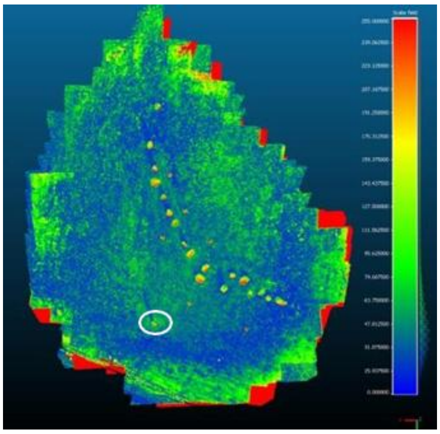
As multiple datasets and data types had been produced, it was necessary to combine them to analyse them. This was achieved in various ways. First, each 3D model was visually analysed and annotated, highlighting areas of exposed soil (ground erosion), standing water, and other relevant topographical features. These were then compared to one another in order to see if the areas of ground erosion changed in size, or if the amount of these patches of exposed soil changed.

Next, the digitised visitor route lines were overlaid onto the aerial view of each site's 3D model. **Figure 6a** shows an example of visitor routes overlaid onto a 3D model of Long Meg. Overlaying the digital layers was completed using PowerPoint (Microsoft, 2025), setting the 3D model as the back layer and the visitor route lines as the front layer of the image.

The 3D models were also analysed using CloudCompare (CloudCompare, 2025) by taking two point clouds (a group of data points which form the basis of a 3D model) of the same site and inputting them into the software. The two separate point clouds were aligned together, and then the software processed them to produce a coloured model, where the colours indicate the degree of difference between the two models. **Figure 6b** shows an example of a CloudCompare (CloudCompare, 2025) model produced through this research, comparing two point clouds from Long Meg, one from 3rd April 2023 and the other from 12th November 2023. Digitised visitor routes could also be overlaid onto CloudCompare (CloudCompare, 2025) models, providing the ability to further compare the visitor routes to physical changes recorded on the sites.

By carrying out the visitor surveys at different times of day across different seasons, it was possible to identify quiet times on site and more popular times, including special days of the year. Using the digitised visitor route maps, it was possible to identify the total number of routes recorded at a site and the number of routes that intersect areas of ground erosion.





(a) **(b)**

Figure 6. a) Visitor routes overlaid onto a 3D model (Metashape Standard) of Long Meg. b) CloudCompare model comparing point clouds from 3rd April and 12th November 2023 at Long Meg.
Source. Agisoft (2025); CloudCompare (2025)

4. Results

The results of the site surveys showed that over time, there were visible changes to the ground surface, especially areas of ground erosion and standing water. The results also showed that areas with high foot traffic occurred in areas showing ground erosion. The example presented in this paper is Long Meg; at the tall standing stone, there is a consistent area of exposed soil. As shown in **Figure 6a**, there is an area of high foot traffic around the tall standing stone where visitors are drawn to this focal point. **Figure 6b** shows the CloudCompare (CloudCompare, 2025) model at Long Meg, comparing site survey results from 3rd April and 12th November 2023. In this model, blue indicates little difference between the two datasets, and green shows a greater degree of difference. The red areas are where the two models have not aligned. The model shows an area of green around the tall standing stone (circled in white). Within the stone circle, there is a large area of green, where the vegetation has changed. From May to October, cows graze within the stone circle, reducing the height of the grass, which could be the reason why areas of vegetation are showing changes in the CloudCompare (CloudCompare, 2025) model.

Figure 7a shows a photograph on site at Long Meg, and **Figure 7b** shows a 3D model generated of the same area. This provides an indication of the detail gathered by the aerial photogrammetry process, and areas where texture or materials can be blurred due to the quality of the photographs collected and the angle at which they were taken. In **Figure 7b**, some of the stones show grass on their side where there are shadows; however, the 3D model usefully shows areas of ground erosion which are present in the photograph. (**Figure 7a)**.

(a) **(b)**

Figure 7. a) Close-up photograph of a stone forming part of the gateway at Long Meg. b) Image of part of the 3D model (Metashape Standard) of Long Meg, focusing on a stone which forms part of the gateway.
Source. Agisoft (2025).

The results of the fieldwork at the five sites provided insight into the locations on each site that were most popular with visitors, and often these areas were undergoing ground erosion. Using the 3D models in conjunction with visitor route maps made it possible to identify this link. At Long Meg, 79.49% of visitor routes recorded were intercepting the area of ground erosion surrounding the tall standing stone pictured in **Figure 5a**.

5. Toolkit

The monetary cost of the monitoring process was a key factor in developing the method and the resulting toolkit, as it was aimed at heritage organisations with limited budgets. The total cost of the equipment and software for the method totalled less than £750 (prices of equipment and software may change over time). This initial cost may be considered high to organisations with limited budgets; however, it is less expensive than repeatedly hiring a contractor to carry out aerial surveys and produce 3D models, or other methods mentioned above for recording the site and visitor behaviour. In addition, once purchased, the equipment can be used as many times as needed by the organisation.

A cost-effective toolkit was produced after the methodology was tested, providing step-by-step instructions for how to carry out the methodology, including guidance on the use of the different software. The toolkit is presented in an A4 booklet. A set of pre-survey tasks is included to ensure the user has gathered certain necessary information about the site they wish to monitor, along with a glossary of terminology used throughout the toolkit. The users of the toolkit must accept responsibility for gaining permissions, UAV insurance, risk assessments, and adhering to CAA regulations. The toolkit takes the user through the visitor monitoring decision-making process, ruling out unnecessary steps to the method if not needed (e.g., if a site does not allow visitors, the visitor monitoring is not needed). The method for monitoring visitor routes and numbers is then set out in a step-by-step flow diagram. Next, the process of decision-making for the UAV site surveys is presented in a flow diagram, followed by the instructions for the aerial surveys. Finally, the toolkit presents the data analysis methods in flow diagrams, and at the end are appendices presenting instructions for use of Dronelink (Dronelink LLC, 2024), Metashape Standard (Agisoft, 2025), and CloudCompare (CloudCompare, 2025).

The toolkit was tested by Nenthead Mines Conservation Society (Nenthead Mines, n.d.), a heritage organisation that manages and maintains a lead and zinc mine site near Alston, Cumbria. By using the toolkit, Nenthead Mines Conservation Society successfully produced visitor route maps and 3D models of their site. The organisation found that the toolkit helped them to understand visitor journeys and identify areas of erosion on the site. In particular, they identified areas of water damage, which the toolkit has helped them monitor. They also provided feedback on the toolkit and suggested some improvements and potential expansions for it. The toolkit is now being refined and finalised, with the aim of it being shared with other organisations in the heritage sector.

6. Discussion

6.1. Strengths

A key strength of this method for monitoring the condition of outdoor heritage sites and visitor behaviours is its replicability. The researcher can reuse the equipment as many times as needed with no extra cost. This would appeal to voluntary groups and heritage organisations with limited resources wishing to gain data about their site over a long period of time. The visitor recording methods are low-cost and easy to teach to staff and volunteers, and the UAV flight uses entry-level equipment and easy-to-use flight planning software. The successful testing of the method by Nenthead Mines Conservation Society showed that the instructions in the toolkit were easy to follow and produced useful results. In addition, the method can be used at a range of site types. It is not confined to only being used at sites in Cumbria or the UK, but has the possibility of being used at heritage sites worldwide.

The potential benefits of this method include the use of the resulting images outside of the main purpose of the research itself, including replicating 3D models for outreach and educational projects, widening access to the heritage site and its associated stories to remote audiences. The use of this method by small heritage organisations will help align their records with those of larger organisations such as Historic England, who use photogrammetry to record a range of different heritage assets under its guardianship (Historic England, 2017).

The method records useful data, providing a record of the site and popular areas of it, which can be referred back to when comparing future results of site surveys. It provides results that can be interpreted and analysed to better understand the potentially vulnerable areas of heritage sites. Having this knowledge can then aid in decision-making around implementing strategies to better manage the protection of vulnerable areas on site, such as the installation of interpretation panels in specific areas to draw visitors away from vulnerable areas. The visitor route data is also useful in assessing the efficiency of existing management strategies, such as the location of site entrances and their impact on visitor flows (Cvelbar, 2018), or how effective the placement of interpretation panels is at channelling foot-traffic.

It also provides a set of documented evidence of visitor numbers (how popular the site is) and the potential visitor impact on the site. These results can be used to support the organisation's future funding applications and interpretation strategies. In addition, the method successfully provides a method to monitor losses of heritage assets over a period of time, which is seen as a requirement for better understanding the future of our cultural heritage (Sagger et al., 2021).

6.2. Weaknesses

There are a range of weaknesses of this method, which future developments will aim to reduce. To fly a UAV, dry and non-windy weather is required, so it may not be possible to gather aerial images during wetter seasons. This was a limitation experienced when the researcher carried out the fieldwork. In addition, a budget needs to be set aside for the equipment and software costs needed for this research, as even though it was designed to be cost-effective, it still requires the purchase of equipment and a time commitment.

The chosen method has limitations in the level of detail it can provide at ground level. As shown in **Figure 7b**, some details are lost in the generation of the 3D models; for example, where the grass level meets a stone, the 3D model blurs these together. This loss of detail in the 3D models limits the ability to interpret results on a small scale (i.e., at the centimetre level), but the 3D model still provides enough detail to identify changes on a site-wide level. The RGB images captured by the UAV camera do not measure the distance from the camera to the ground surface, but the use of multiple photographs to create a 3D model (photogrammetry) provides a topographic rendering for visual analysis. There are sensors available that would collect topographic measurement data, for example, LiDAR (Uribe et al., 2021) However, these were more expensive and less accessible for entry-level users, so they were not used in this research. The repeated use of LiDAR would build a portfolio of models where physical changes to the site could be detected on a finer scale; this level of detail is not required for this research project.

The quality of 3D models generated via aerial surveys (photogrammetry or LiDAR) depends on the Ground Sampling Distance ('GSD') (Historic England, 2017). The GSD is calculated using the sensor's specifications and the altitude of the UAV capturing the data (Pix4D, 2025), with higher altitudes producing lower resolution data and lower altitudes producing higher resolution data (Historic England, 2017). Flying at lower altitudes over a set takes longer than flying over the same area at higher altitudes, and therefore uses more battery power (Pix4D, 2025). This is also a consideration when using aerial surveying techniques.

The paper-and-pencil method for recording visitor routes is based on the observer's perception. This was carried out by one researcher for each of the sites, so the results were recorded in a consistent manner; however, there may be a risk that if routes were to be recorded by numerous different people, they would be inconsistent. A drawback of the paper-and-pencil method was also the time required to digitise the recorded routes (Yalowitz & Bronnenkant, 2009).

6.3. Opportunities

This method has a range of opportunities generated alongside the main body of results. The 3D models produced can have a range of uses, not just for evidencing physical changes at sites. Other uses include marketing for heritage sites, by showing the 3D models on screens at the site or on the site's website. 3D models can be used for virtual tours of the site online or in Augmented and/or Virtual Reality. The 3D models could also be 3D printed and used for merchandise for heritage sites, the sales of which could raise money to help maintain the site.

In addition, the toolkit can be adapted for other issues that are not yet covered by it. For example, it can be used specifically to monitor water damage on sites. In addition, the aerial images gathered can be used for wider research in fields such as archaeology, archaeoastronomy, digital heritage, ecology, and more. The research can provide a basis for cross-disciplinary studies into heritage sites.

Improving the method and the toolkit in the future, whilst ensuring it remains cost-effective, may be possible as more sophisticated technologies become cheaper, for example LiDAR on UAVs, which will enable greater detail of sites to be captured for the generation of 3D models and can be used in conjunction with the existing photogrammetry method to enhance the quality of the data collected (Historic England, 2017).

6.4. Threats

There are also a number of threats to the method. For example, in the future, the CAA may increase its requirements regarding the flight of UAVs. In addition, some of the software providers may change the nature of payment, i.e., switching from a one-off cost to a subscription plan for use of the software, which may prove to be more expensive. These threats may increase the time and cost of monitoring outdoor heritage sites.

The site monitoring process requires a person to pilot the UAV, so it is useful to have more than one person trained to do so, in case a pilot is unavailable to carry out the flights on a regular basis. The visitor monitoring process requires data to be gathered in-situ over periods of time in the outdoors, which may not be appealing to some staff and volunteers, which could impact the amount of visitor data collected.

6.5. Key outcomes

Overall, the strengths of the method outweigh the weaknesses, as it provides a cost-effective way of monitoring the loss of heritage assets at outdoor sites, as confirmed by the external trial user, Nenthead Mines Conservation Society. All of the sites presented different challenges and characteristics; however, the method applied was able to successfully capture the physical site condition and the visitor data to a consistent quality. The period of monitoring could be made less frequent, or remain the same, but continue on an ongoing basis, so eventually a dataset allowing comparisons in physical changes to a site and visitor behaviours over a period of years, rather than months, can be made.

7. Conclusion

The methodology was designed to monitor changes in the physical condition of heritage sites and to record visitor routes at these sites. This led to the development of a cost-effective toolkit to assist heritage organisations with limited financial resources to be able to monitor their sites. The method included repeated recording of visitor routes around the site, logging visitor numbers, and carrying out aerial photogrammetry multiple times over a set period to record changes in the condition of the site. The method used accessible equipment aimed at first-time users, which was able to collect clear data to produce useful results to enable the analysis of site-wide physical condition changes and visitor route trends. The researcher developed the methodology and tested it at five sites in Cumbria before designing a toolkit based on the results of the fieldwork. An external heritage organisation, Nenthead Mines Conservation Society, then tested the toolkit at their site and provided feedback to the researcher on the clarity, ease of use, and results of the toolkit, and any improvements or potential expansions to it.

Weaknesses of the method, such as the need to purchase equipment, could be resolved by funding opportunities, collaborations with other heritage organisations to share equipment, and supporting each other's fieldwork. Even though the method uses RGB imagery, rather than multispectral imaging, it produces 3D models of a quality that shows physical changes to the site over time. The 3D models provide a site overview and can be visually analysed to highlight areas of ground erosion, and when analysed in conjunction with the visitor route maps, can provide information about how areas of high footfall are impacting the state of the ground surface. This level of detail is suitable for assessing changes in the physical condition as detected by visual and digital analysis of the 3D models. As the 3D models are produced via RGB aerial photogrammetry, without the addition of LiDAR, they do not take laser-scan measurements of the site topography, so there is a limit to the detail that can be gathered by this method.

However, for a site-wide monitoring technique and a method of providing an overview of a site's condition, aerial photogrammetry, as used in the methodology, was effective.

The method for the visual analysis is accessible to entry-level users of the method, with the digital analysis being slightly more complex, but the step-by-step instructions provided in the toolkit make it an accessible tool for first-time users of CloudCompare (CloudCompare, 2025).

The results from recording routes of visitors provide up-to-date data on areas of high and low footfall across a site. In addition, the method of recording visitor routes is a simple and low-cost method, which does not require costly equipment and lengthy training. However, due to the use of a more basic method, this method can be impacted by observer bias. To avoid inconsistency in recording visitor routes, training and practice sessions could take place to teach teams how to best apply the paper-and-pencil method in-situ. During these training sessions, comparisons of what different researchers have recorded could be shown to participants to highlight potential areas of inconsistency. Using a map which clearly shows the features of the site, e.g., walls, will help to researchers record where visitors have walked in relation to features on the site. As the recording of visitor routes and numbers takes place over a long time-scale, small inconsistencies and anomalies will become statistically negligible, with data showing the general trends more than individual impact. The rationale for choosing the paper-and-pencil method was to provide a simple and low-cost technique for data collection, which would produce new data about the site over a long period of time.

In conclusion, the method has proven to be a useful and cost-effective way of recording site condition and visitor routes on a repeated basis over a set period of time. The combined method of using aerial photogrammetry and the paper-and-pencil technique to record visitor routes and numbers has proven successful in providing records of a point in time over a period of months. The results gained from aerial site surveys and gathering visitor data over time allow comparisons to be made and tracking of changes over time to physical site condition to be possible. Although a finer level of detail is not gained with this method, it provides an entry-level way for small voluntary heritage organisations to record and monitor the sites under their care and produces results that can be easily interpreted. Additional benefits of the method include the wide-ranging potential uses of the 3D models of the sites for outreach, developing digital twins, and merchandising. The toolkit will help enable managers of heritage sites to monitor loss of heritage assets, in line with the requirement that was outlined by the DCMS (Sagger et al., 2021). The process of developing the toolkit has prompted ideas for its expansion and potential future applications in the heritage sector and beyond.

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Conflict of interest

The author(s) declare(s) that there is no competing interest.

Glossary

3D model: A three-dimensional (3D) representation of a subject (e.g., a heritage site) in digital form, created using imagery and/or measurements of the real subject fed into specialist software (Gidusko, 2018).

Aerial photography: Capturing photographs with a camera from above the subject using both vertical and oblique angles (Historic England, 2017).

CloudCompare: A free software used to compare two point clouds and produce a colour-scale image showing the degree of difference between the two point clouds (CloudCompare, 2025).

LiDAR: Light Detection and Ranging (LiDAR) is a technology for mapping that emits laser pulses and calculates distance by measuring the time taken for the pulse to reflect back to the sensor (Historic England, 2017).

Paper-and-pencil method: A method of tracking and/or timing, by writing or drawing on paper with a pencil (Yalowitz & Bronnenkant, 2009).

Photogrammetry: The use of 2D photographs taken of one subject (with overlap) at different angles, which are processed using specialist software to generate a 3D model of the subject (Gidusko, 2018; Bhambri, 2016).

Point cloud: A digital collection of points that form the surfaces of digital 3D models (Historic England, 2017).

UAV: Unmanned Aerial Vehicle, also known as an Unmanned Aerial System or a drone, is an aircraft that can be piloted remotely (Historic England, 2017).

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