Long Paper

Light at the End of the Tunnel?

The Application of Real-World and Digital Approaches on the A303 Amesbury to Berwick Down (Stonehenge) Scheme

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Abstract: The A303 Amesbury to Berwick Down (Stonehenge) road improvement scheme crosses one of the most famous prehistoric landscapes in the world. Known for its iconic stone circle, henge monuments and cursuses and the densest concentration of burial mounds in Britain, the area around Stonehenge was designated a World Heritage Site (WHS) in 1986 in recognition of its outstanding universal value. The design and planning process for the proposed road improvement scheme has required an in depth and detailed understanding of the likely sensory experience and perception of a multi-faceted engineering project within a complex archaeological landscape. To meet this challenge, the assessment team used a range of digital tools to assist their work. These included visually verifiable montages, virtual reality models with 360-degree visualisations explorable in augmented reality, animated drive-throughs of the scheme, auralisation experiences, and an interactive digital Environmental Statement. These digital approaches were key to analysing and managing large heritage datasets, and for engaging with key stakeholders and the wider public. Building a multidisciplinary expert team, including digital innovators, from the outset was essential to the project, both to inform the environmental impact assessment, the heritage impact assessment on the outstanding universal value of the World Heritage property and the engineering design, and to convey complex information in an accessible manner to multiple stakeholders and audiences.

Keywords: *World Heritage Impact Assessment—Virtual and Augmented Reality—Auralisation—Computer Generated Imagery—Digital Environmental Assessment*

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Introduction

The A303 Amesbury to Berwick Down (Stonehenge) road improvement scheme traverses one of the most iconic prehistoric landscapes in the world. Known for its monumental stone circle, and the densest concentration of burial mounds in Britain, this well preserved and extensive archaeological landscape was designated a World Heritage Site (WHS) (Figure 1) in 1986 (HBMCE, 1985).

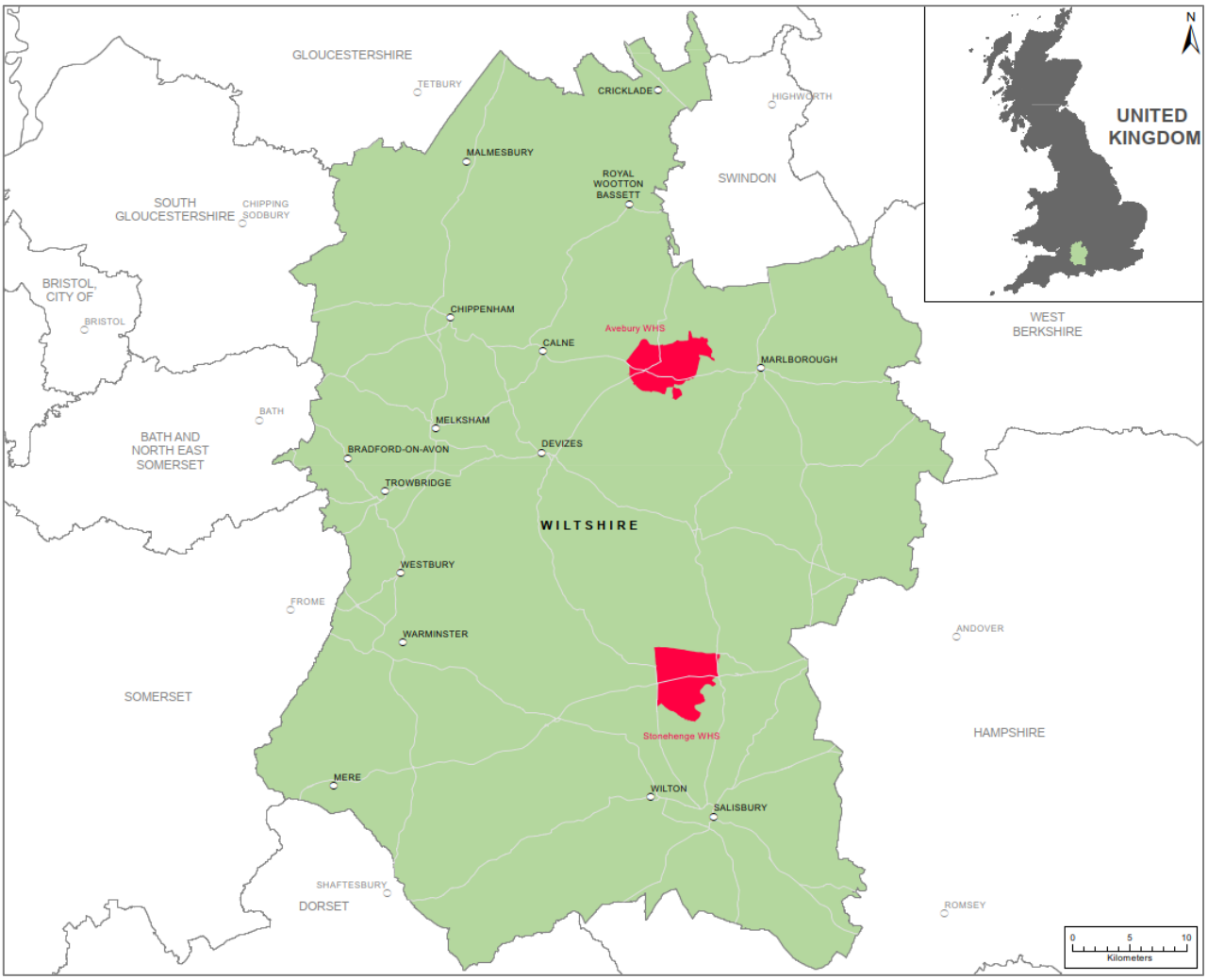

Fig. 1. Location of Stonehenge, Avebury and Associated Sites World Heritage Site. Data (© Historic England 2022. Contains Ordnance Survey data © Crown copyright and database rights. The Historic England GIS Data contained in this material was obtained in 2022. The most publicly available up to date Historic England GIS Data can be obtained from HistoricEngland.org.uk. © Crown copyright and database rights 2017 Ordnance Survey License 100030649).

The existing A303 passes within 165 m of the Stonehenge monument, impacting its setting and cutting the stones off from much of the surrounding ancient landscape and the many prehistoric monuments, causing visual intrusion, noise and air pollution, and affecting visitor access and safety. Various plans to alleviate congestion past Stonehenge have been put forward since 1991. These schemes were inevitably controversial, raising concerns and igniting passionate debate. The present scheme aims to address the impacts of the existing A303 and contribute to the wider aims of the WHS Management Plan to improve access across the WHS landscape.

Following the announcement of the preferred improvement option by National Highways (formerly Highways England) in 2017, an outline design was developed and subsequently subjected to a multidisciplinary Environmental Impact Assessment (EIA) which included cultural heritage as a topic (Highways England, 2018a), and a WHS Heritage Impact Assessment (HIA) (Highways England, 2018b), as part of the planning application. Under the current planning regime, approvals for nationally significant infrastructure projects in England, such as the A303 road improvement scheme, are subject to granting by the UK Government of Development Consent Orders, following public exami-

nation. The A303 Amesbury to Berwick Down road scheme proposed by National Highways is located in Wiltshire in southern England. One of the UK's first World Heritage Site nominations, the Stonehenge Avebury and Associated Sites WHS was inscribed in 1986, and comprises two discrete areas separated 30km apart, centred on the prehistoric landscapes of Stonehenge and Avebury. The A303 scheme is located within and adjacent to the Stonehenge portion of the WHS.

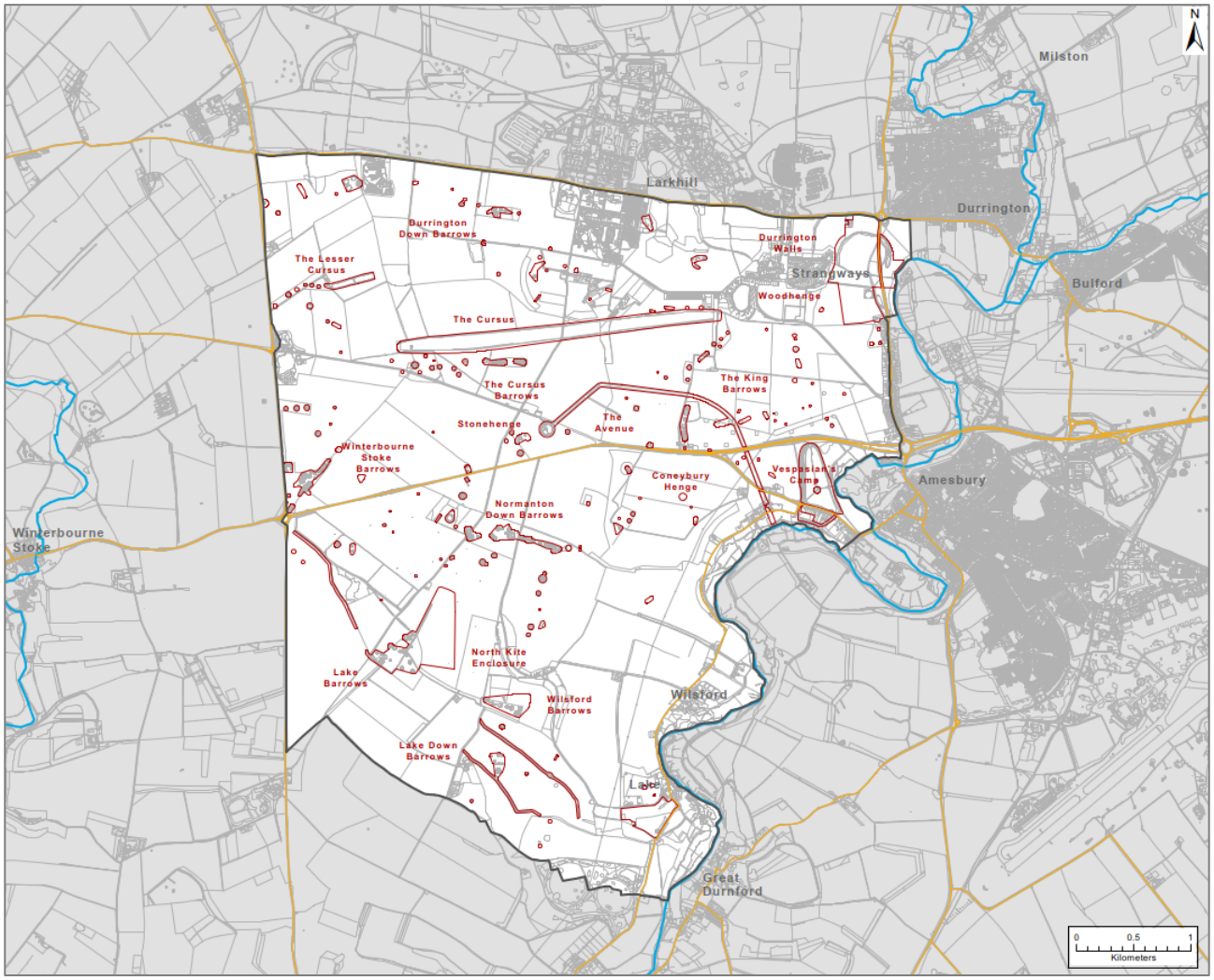

Fig. 2. Location of scheduled monuments in the Stonehenge, Avebury and Associated Sites World Heritage Site. Data (© Historic England 2022. Contains Ordnance Survey data © Crown copyright and database rights. The Historic England GIS Data contained in this material was obtained in 2022. The most publicly available up to date Historic England GIS Data can be obtained from HistoricEngland.org.uk. © Crown copyright and database rights 2017 Ordnance Survey License 100030649).

The Stonehenge part of the WHS is an outstanding prehistoric landscape dating back over 5000 years to the Neolithic and early Bronze Age, noted for the exceptional survival of prehistoric monuments and sites (Figure 2). Stonehenge is perhaps the most famous and sophisticated stone circle in the world, aligned on the solstice sunrise and sunset. The monument is set in a highly complex archaeological landscape which contains many other prehistoric monuments, such as the Avenue, the Cursus, Woodhenge and Durrington Walls. The wider landscape contains the densest concentration of Neolithic and early Bronze Age burial mounds in Britain – there are over 350 within the WHS – an exceptional number.

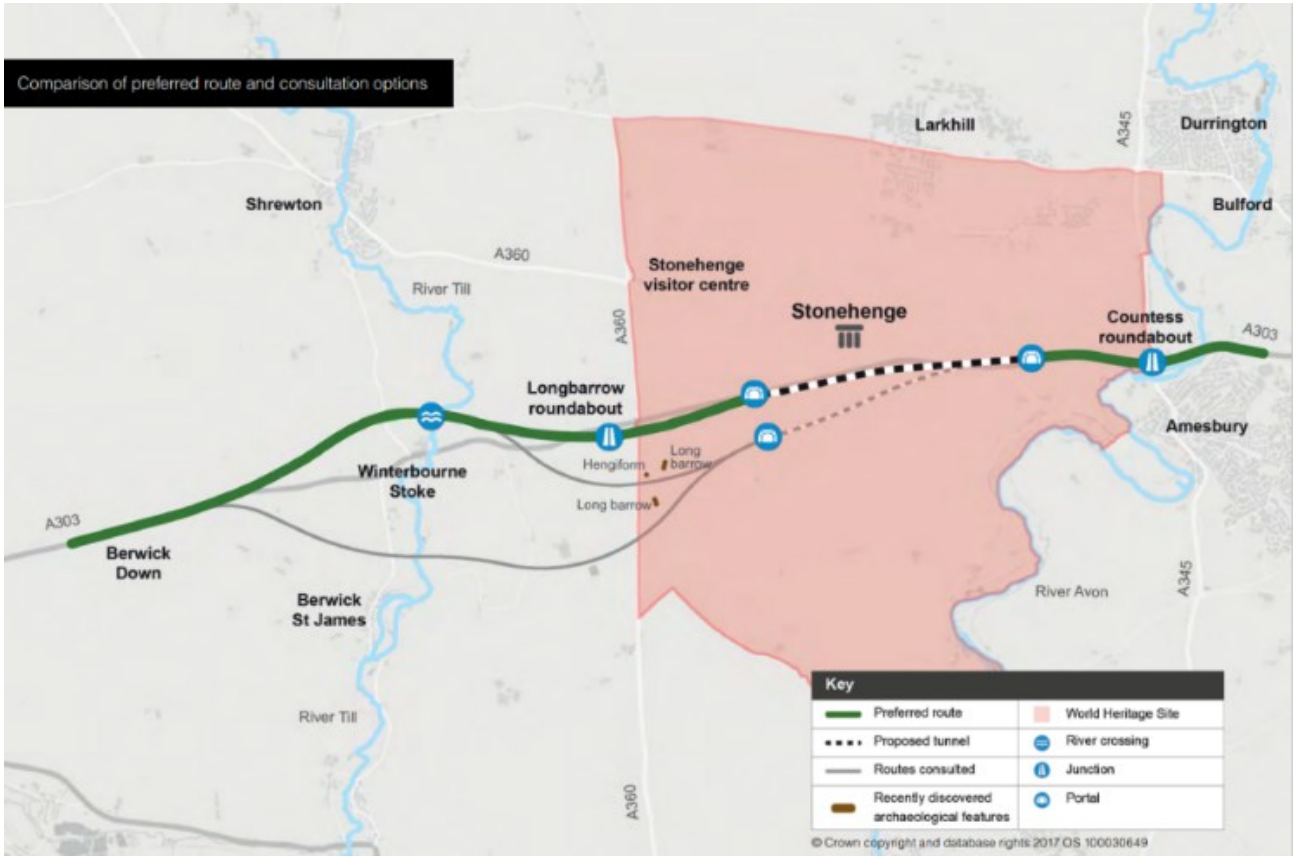

Fig. 3. Scheme options and preferred route announced in 2017 (© National Highways (formerly Highways England)).

The assessment of improvement options for the A303 Amesbury to Berwick Down road scheme was carried out between 2016 and 2017 (Figure 3). The road scheme is part of a planned programme of regional road improvements for the A303 corridor in the southwest of England. Proposals for the improvement of the A303 between Amesbury and Berwick Down have been the subject of extensive study and consultation since 1991. The process of options identification and route selection leading to the scheme has included options both with and without tunnelling in the WHS. Sixty route options have been considered. The current proposal involves the construction of a tunnel past the Stonehenge monument.

National Highways' proposals are for a new section of road approximately 13 km long, with a 3.3 km twin-bore tunnel concealing the infrastructure within the landscape, with portals and approach cuttings within the World Heritage Site; a northern bypass for the village of Winterbourne Stoke west of the WHS, including a viaduct over the River Till valley; and improvements to existing junctions (Highways England, 2018c). The scheme avoids newly discovered sites, including two Neolithic long barrows and a hengiform enclosure, which were discovered by geophysical survey. Its configuration also avoids road lighting or the glow and glare of vehicle lights intruding on the view of the setting sun from Stonehenge during the winter solstice. This is perhaps the most important sightline in the WHS. Parts of the route had previously been surveyed for an earlier scheme proposed in 2004, reducing the risk of encountering as-yet undiscovered archaeology.

Development of the outline design between 2017 and 2018 involved extensive and regular engagement with relevant stakeholders to inform the development and assessment of the design for the

scheme. These stakeholders include Wiltshire Council, English Heritage, Historic England, The National Trust, the Environment Agency, Natural England, and the Amesbury and Winterbourne Stoke Parish Councils.

The application for a Development Consent Order (DCO) was submitted in October 2018 (National Infrastructure Planning, 2021). Following public examination in 2019, in January 2020, the Planning Inspectorate recommended that the DCO should be refused. Following the granting of development consent by the Secretary of State for Transport in November 2020, a judicial review was brought and an Order of the High Court in July 2021 quashed the Secretary of State's decision. The DCO application was redetermined by the Secretary of State in July 2023 and a second judicial challenge in December 2023 was unsuccessful.

Assessing scheme impacts

The potential impacts and effects of the scheme on archaeology and cultural heritage were assessed in line with national and international requirements for EIA. Assessment considered scheme impacts on individual heritage assets and their settings through the formal EIA process. This was reported in an Environmental Statement setting out a cultural heritage impact assessment for archaeology, built heritage and historic landscape, and in a WHS Heritage Impact Assessment evaluating the effect of proposals on the Outstanding Universal Value (OUV), Integrity and Authenticity of the World Heritage property (UNESCO 2013, pp. 291–94).

The Environmental Statement was undertaken in accordance with the Design Manual for Roads and Bridges for England, and the requirements of the Town and Country Planning (Environmental Impact Assessment) Regulations 2017. The Heritage Impact Assessment followed ICOMOS Guidance on Heritage Impact Assessments for Cultural World Heritage Properties (ICOMOS, 2011). The iterative EIA and HIA processes informed scheme design and mitigation proposals. Assessment work was systematic, methodical and transparent; this controversial scheme was subject to extensive peer review and public scrutiny.

Project team and stakeholders

Assessing the scheme impacts involved multidisciplinary EIA. The project team was a collaboration of environmental design team consultants drawn from the three joint venture companies involved in the scheme – AECOM, Mace and WSP (AmW). AmW's multi-disciplinary team included specialists in cultural heritage and archaeology, biodiversity, noise and vibration, air quality, traffic, landscape and visual impact, geospatial data and visualisation, working alongside the engineering design team. AECOM's heritage team also worked with experienced local fieldwork specialist Wessex Archaeology.

Multiple stakeholders were involved at international, national, regional and local level, including government and non-governmental organizations, experts, the heritage sector, academia and civil society. Multiple stakeholders included:

- UNESCO World Heritage Centre and ICOMOS
- Department for Digital, Culture, Media & Sport and Department for Transport

- WHS Partnership Panel, Steering Committee and Coordination Unit, and Avebury and Stonehenge Archaeological & Historical Research Group
- A303 Heritage Monitoring and Advisory Group – Historic England, Wiltshire Council, English Heritage Trust and The National Trust
- A303 Scientific Committee – an independent academic expert advisory panel
- A303 Local Community Forum and the members of the wider public – local, national and international
- Religious groups and others who venerate and enjoy the WHS landscape
- Archaeological and heritage societies

Real world approaches

Establishing the cultural heritage baseline

There have been many previous archaeological and antiquarian investigations at Stonehenge and in the surrounding landscape, dating back to the 1620s. The area's monuments and landscape have influenced the development of archaeological science as well as influencing architects and artists, literature and popular culture. An extensive search of previous research was undertaken and the emerging results of recent and ongoing heritage site prospection, fieldwork and research programmes in the area were reviewed.

The assessment team established the designated and non-designated heritage baseline using Historic England's National Heritage List for England and the Wiltshire and Swindon Historic Environment Record. There are over 700 known archaeological features and find spots, as well as 175 nationally scheduled sites recorded in the Stonehenge part of the WHS (Simmonds and Thomas, 2015, para. 2.2.4).

Assuming that astronomical sightlines were once largely unobstructed in the Neolithic and Bronze Ages, it was considered important to try and ensure that the integrity of sightlines is maintained today. The indicative location of astronomical sightlines (Chadburn and Ruggles, 2017) was considered in the 2018 outline design. Dark skies were also perceived to be relevant to understanding the experience of OUV. The assessments considered the wider surrounding environment, including the impact of light spill and tranquillity mapping. Work on noise modelling also helped to identify locations for the baseline monitoring of heritage assets and visitor hotspots.

Intervisibility modelling, ground truthing and setting assessment

The project team undertook an extensive walkover survey over the course of two years and in different seasons. The overall spatial scope of the survey was complex, focused on a 2 km wide linear corridor, but also including the Stonehenge part of the WHS and the landscape beyond. Every heritage asset potentially impacted by the scheme – whether an upstanding structure, visible earthwork, or buried archaeological site – was visited to verify its condition and integrity, its physical surroundings and its relationships with other sites, as well as its setting (Figure 4). Setting assessment and inter-visibility modelling was informed by Zone of Theoretical Visibility (ZTV) modelling; using both

bare-earth and vegetated models. Professional geo-located photography was used to form the basis of visually verified photomontages from key locations.

Extensive assessment of the setting of heritage assets was undertaken (Historic England, 2017; ICOMOS, 2005). This involved identifying and assessing the significance of sites and their connections to each other and the surrounding landscape to understand how their setting contributed to their significance. Setting assessment considered a wide range of factors including:

- static and moving viewpoints
- key sightlines, skylines, astronomical and solstitial alignments
- inter-visibility between monuments and inter-relationships
- relationships with topography, ridge lines and dry valleys
- hidden severance and implied relationships
- contextual relationships – cultural, intellectual, spatial and functional
- our understanding of the historic relationship between places
- subjective experience
- ambient noise, dust and vibration
- dark skies and light pollution
- modern land use, infrastructure and intrusion
- modern access routes and visitor experience

This provided a comprehensive, real-world approach to understanding impacts on heritage assets and their settings, their contribution to Attributes of OUV, and impacts on the OUV, Authenticity and Integrity of the WHS.

Archaeological field survey and evaluation

A comprehensive and research-driven suite of evaluation surveys were undertaken in stages. The surveys informed both the impact assessments and the development of the outline scheme design and embedded mitigation design, and helped to focus proposals for further mitigation. The team assessed the relevance and quality of previous archaeological investigations associated with the road scheme and, in some cases, chose to repeat non-intrusive work, such as geophysical survey, to supplement the earlier work from the 1990s and 2000s. Areas of previous trial trenching were augmented to corroborate results. The survey programme sought to minimise intrusive work within the WHS, in line with the conservation requirements of the WHS Management Plan (Simmonds and Thomas, 2015).

Multiple survey techniques were employed to provide comprehensive coverage and understanding of the hidden landscape. These included ploughzone artefact sampling (surface artefact collection, sieving of topsoil samples), geophysical surveys (detailed magnetometer, electrical resistivity, ground penetrating radar, downhole electrical resistance tomography – including data shared by research projects) and archaeological trial trenching (archaeological excavation and recording, environmental sampling and assessment, and geoarchaeological and palaeo-environmental sampling and assessment). Fieldwork results were mapped on a project WebGIS accessible to the whole

project team, in order to analyse multi-layered information and large datasets. This meant data could be readily shared with other environmental disciplines and the engineering design team, as well as the statutory heritage stakeholders and academic advisers.

Independent monitoring of fieldwork was undertaken by the statutory heritage authorities and site visits were undertaken by the A303 Scientific Committee. Inputs from heritage stakeholders (Heritage Monitoring and Advisory Group, with representatives from Historic England, Wiltshire Council Archaeology Service, English Heritage and The National Trust) and academic advisors (Scientific Committee) were essential to assure the design, methodology, quality and integrity of the evaluation fieldwork. This advice was essential to fine-tuning the evaluation design and making the most of the research potential of the evaluation stage of investigation.



Fig. 4. Undertaking setting assessment near the Stonehenge monument (© AECOM).

Digital approaches and tools

To assess potential scheme impacts on the OUV of the WHS, it was imperative to understand the significance of individual heritage assets and asset groups, their contribution to the Attributes of OUV, Authenticity and Integrity of the WHS, and potential scheme impacts and effects on OUV. Understanding the likely sensory experience and perception of various versions of a multi-faceted engineering scheme within such a highly complex landscape was not easy. The assessment team used the following digital tools:

- Visually Verifiable Montages
- Virtual Reality (VR) app, with 360-degree CGI visualisations explorable in Augmented Reality (AR)
- animated drive-through models
- auralisation (sound demonstration) techniques
- an interactive, purpose-built digital Environmental Statement



Fig. 5. Visually Verifiable Montage photography near the Stonehenge monument. (© AECOM).

These digital tools were used to enable the integration of heritage and design data, responding rapidly to the evolving scheme design. This enabled transparent access to heritage data for all technical disciplines, stakeholders and for the public. These tools made noise and visual impact easier to understand and more accessible to a wider demographic, helping to communicate key facts. Digital tools conveyed complex design changes and issues to the public in a readily understandable way.

Accurate *Visually Verifiable Montages (VVM)* were created for key viewpoints in the landscape (Figure 5) in late 2017 / early 2018. The photomontages were created according to formal landscape and visual impact assessment guidelines (Landscape Institute, 2011; Landscape Institute, 2017). They aided the objective evaluation of changes to the skyline, surrounding areas and the setting of heritage assets. This enabled an understanding of how the scheme would sit within the landscape following construction, and how it would interact with monuments, topography and inter-relationships across the WHS. The VVMs depicted the current situation; then the appearance immediately post-construction; and then 15 years after construction, when scheme planting would be fully established.

Computer Generated Imagery (CGI) was used to create an interactive, immersive *VR app* within which a digital base model of the existing landscape was created, based on digital terrain data and aerial photographs. The scheme model was integrated into the CGI visualisations. It included a laser scan of the Stonehenge monument (Figure 6) to create a 3D representation within the model (AECOM, 2018).

For selected viewpoints in the landscape, *360-degree CGI visualisations* were created to show the current situation and how it impacted the monuments, and how the view would change if the scheme was constructed. The viewer could turn through 360 degrees to explore the scheme changes in AR using tablet computers and VR headsets (AECOM, 2018). This was used at the UNESCO / ICOMOS

Advisory Mission (March 2018) and at the local public consultations. This enabled the Advisory Mission, consultees and the general public to consider changes at key points in the landscape and helped to foster informed dialogue and the exchange of ideas.

In an industry first, AECOM's cutting-edge auralisation (sound demonstration) techniques were used to communicate the soundscape changes resulting from the scheme (March 2018). Ambient traffic noise was recorded at key points in the landscape, and AECOM's Immersive Sound Studio was used to simulate how the soundscape would change at that key point. New techniques were developed to remove existing traffic noise from the ambient sound recordings and to auralise the sound of traffic on the realigned or upgraded road. This allowed listeners to perceive sound sources / simulated changes at the desired sound level, direction and distance via headphones or a group of loudspeakers at events (Figure 7). This was the first time pioneering immersive sound demonstrations were deployed during statutory public consultation for a UK major road scheme. Auralisation techniques allowed a wide range of people to understand the current noise levels and consider how they would change following scheme construction.

Animated drive-throughs were also created for the public consultations in 2017 and 2018 and revised in 2020 (AECOM, 2020). These involved digitally recreating the existing landscape including the scheme's 3D Building Information Model (BIM), animated traffic and a mosaic of high-resolution aerial images. Scenes were created in Autodesk 3ds Max, and V-Ray was used for rendering. This collaborative, data-rich animation enabled a photorealistic representation of driving along the constructed scheme and the view of the landscape beyond, with animated traffic for scale and perception (Figure 8).

In another innovation, AECOM produced the UK's first purpose-built *digital Environmental Statement* (Figure 9) for the scheme (AECOM, 2019). This transforms the way complex environmental data, information and assessments are presented and shared with stakeholders, bringing environmental data together seamlessly. By combining reports, spatial data and visualisations, the digital Environmental Statement integrates over 250 documents and 7,000-pages of the original Environmental Statement to create an interactive and intuitive platform that allows the user to navigate their own way through the full package of environmental information. It makes large amounts of complex project information more accessible and easier to navigate and understand.

Digital technology and creative approaches to communication are also at the heart of community engagement on the project. Working together with BlockBuilders C.I.C. and AECOM's archaeology specialists, National Highways developed a *Minecraft: A303 Stonehenge Through the Ages* game (Figure 10) and lesson plans for the scheme (National Highways, 2021). Launched in September 2021, this forms part of a series of National Highways Minecraft games that aim to engage pupils in learning about STEM (science, technology, engineering and mathematics) subjects and careers, including archaeology. These Minecraft Education Edition games are aimed at school children aged 7–11 and 11–14. Pupils complete tasks as they are taken on a journey through different periods, with Stonehenge as the backdrop, including the Mesolithic, Neolithic, Bronze Age and Roman periods, the First World War, the present day and the future.



Fig. 6. A303 360-degree CGI visualisations – 3D scan of the Stonehenge monument and exploration of the scheme using Augmented Reality with tablet computers and VR headsets; showing the AR view from the Winterbourne Stoke Crossroads barrow group looking towards the Longbarrow Junction as existing and how it will change (middle images); and using a VR headset looking out from the centre of the Stonehenge monument (bottom image) (© AECOM 2018).



Fig. 7. Sound recording on site and members of the public experiencing the sound demonstation (© AECOM 2018).



Fig. 8. Stills from animated drive-through (© AECOM 2018).

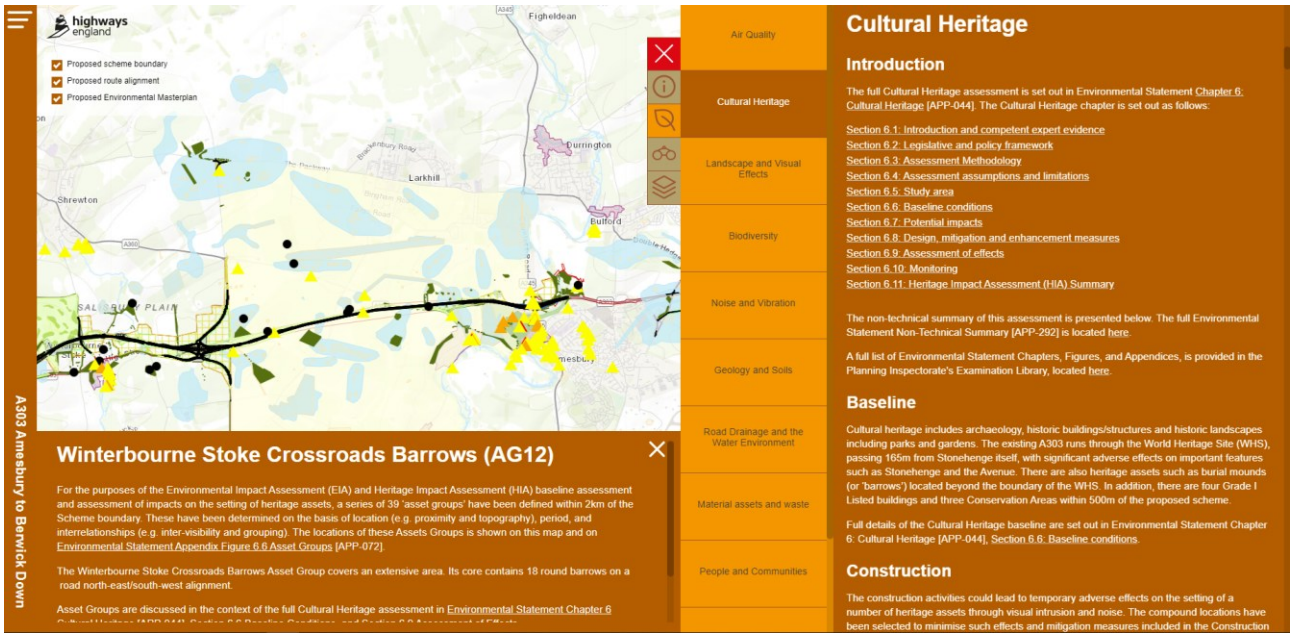

Fig. 9. Digital Environmental Statement user interface (© AECOM 2019).

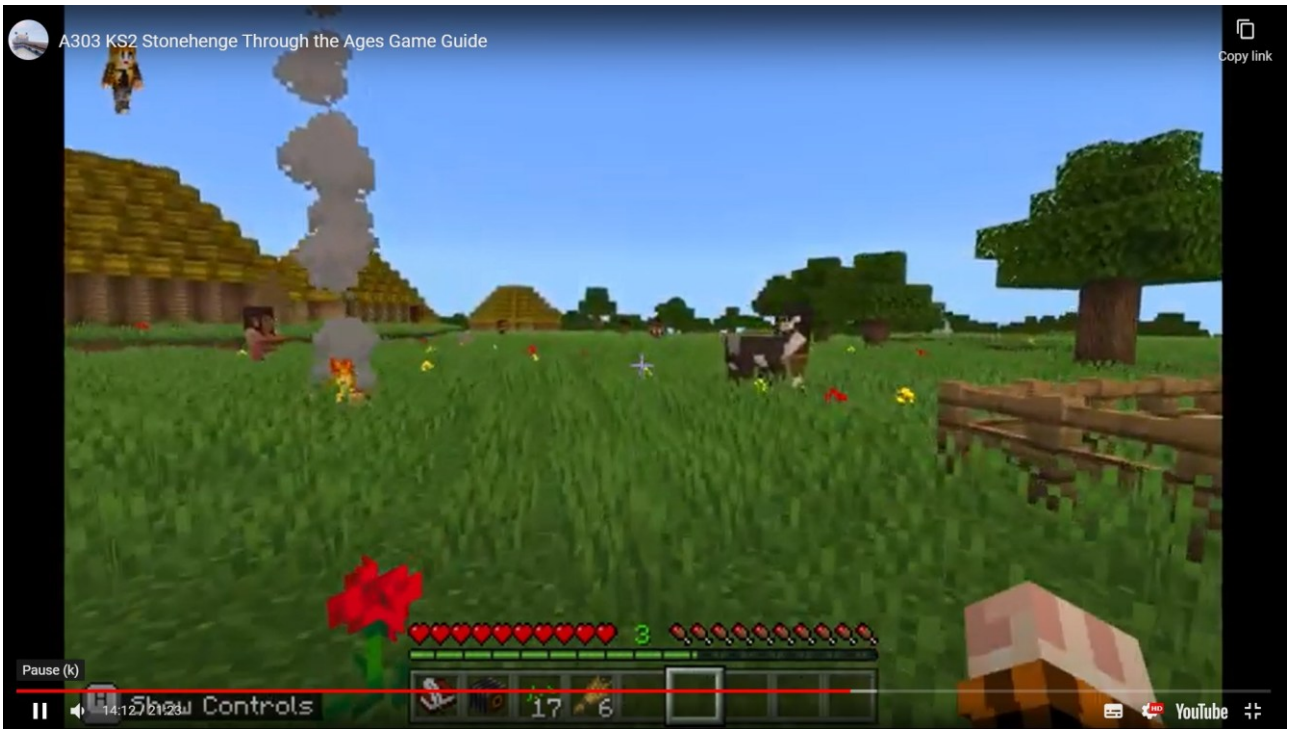

Fig. 10. Still from Minecraft: A303 Stonehenge Through the Ages game guide (© BlockBuilders C.I.C.).

Conclusions

This paper has illustrated how the use of digital technology has been fundamental to design, assessment and public consultation and engagement on this project. Digital technologies have enabled the sharing of heritage data across design and environmental disciplines, enabling integrated, collaborative design, which took account of heritage and environmental constraints alongside engineering parameters. This enabled the informed participation of stakeholders, enabling a heritage-focussed design development process.

The assessment of the potential impacts and effects of the A303 Amesbury to Berwick Down (Stonehenge) Scheme on cultural heritage sites and upon the OUV of the WHS was a complex process.

Complicating factors included the sheer volume and variety of antiquarian and more recent archaeological field survey – and an equally large volume of ever-shifting and competing theoretical interpretations. As ever, extensive data does not necessarily equate to good data, nor to clarity or consensus in understanding the nature and significance of the archaeological landscape.

Understanding the meaning of the landscape to current generations was crucial. Stonehenge is an iconic visitor attraction, and the wider landscape is cherished; many people venerate and enjoy the area. A real-world, people-centred approach is essential to understanding impacts on heritage assets and their setting, including their contribution to Attributes of OUV, Authenticity and Integrity of the WHS.

The scheme has a long and controversial history, with proposals for road improvements going back over 30 years. More recently, digital tools have been used to handle the large amounts of data involved, and to inform and visualise iterations of the scheme as they were developed. These digital approaches were fundamental to analysing and managing vast datasets, and for engaging with key stakeholders and the public. Building an expert team including digital innovators from the outset was essential not only to inform assessment and design, but also to convey complex information on scheme impacts in an understandable way to multiple stakeholders and audiences. The innovative application of digital technologies has improved people's access to data and promoted understanding of the scheme's impact on the world-famous prehistoric landscape.

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Conflict of Interests Disclosure

Cultural heritage impact assessment, archaeological fieldwork strategy and specifications and inputs into scheme design was undertaken by heritage professionals within AECOM, as part of the AECOM Mace WSP (AmW) joint venture, for National Highways. Field evaluations were carried out by Wessex Archaeology for National Highways.

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