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Assessing and predicting natural environmental impacts on cultural heritage landscapes: a case study on Hadrian's Wall (Ref IAP-16-96)

Newcastle University, School of Civil Engineering & Geosciences

In partnership with Durham University, English Heritage and Historic England (CASE Partners)

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Key Words	**Climate change; cultural heritage; data fusion; earth observation; landscape modelling; natural hazards**

Overview

In AD 122 the Roman Emperor Hadrian ordered a wall to be built, dividing Britain in half. Stretching over 117 km (80 Roman miles) from Bowness on the River Solway on the north-west coast of England to Wallsend on the River Tyne in the north-east, it was to become one of the most heavily defended frontiers of the Roman Empire. Hadrian's Wall today is a designated UNESCO World Heritage Site and its landscape is very different from that of Roman times, although significant portions of the Wall are still visible in coastal, rural and urban settings. The remaining fabric and landscape of the Wall are subject to various modern day stresses, for example anthropic drivers such as tourism and urban development, but also natural environmental processes, the focus of this study.

Geospatial temporal analyses and multi-temporal 3D reconstruction are fundamental for safeguarding and maintaining all forms of cultural heritage. Such studies form the basis for any kind of decision regarding intervention on cultural heritage, helping assess the risks and issues involved. The primary reason for estimating temporal change over time is to enable the prediction of future evolution. Whilst the future rate of change of a system in dynamic equilibrium may be assumed to be equal to average historic rates, this is not the case with the uncertainty of climate change. This study will therefore utilise existing multi-temporal 3D datasets to analyse historic change to the landscape of the Wall and will exploit the results using numerical modelling approaches to predict its future evolution.

The overall aim of the research project is to assess the vulnerability of tangible cultural heritage to natural hazards under a changing climate regime, demonstrating this on an iconic monument of international renown. To achieve the aim, the study will address the following objectives:

1. Review the state of the art in spatio-temporal landscape modelling and appraise the suitability of existing and alternative datasets of the Wall;
2. Construct fully integrated, coherent 3D time series for characteristic sites on the Wall that are at risk to natural environmental processes;
3. Extend the time series by predictive modelling of inherent natural environmental processes under different future climate change scenarios;
4. Interpret the impact of historic evolution and future projection on the tangible cultural heritage.

Each objective will be addressed in an independent work package (WP) supported by specialist expertise from different members within the academic

supervisory team and project partners English Heritage (EH) and Historic England (HE).

Methodology

The research will focus on three different study sites (Figure 1) that characterise natural environmental phenomena impacting the Wall in the 21st Century. The fort, civilian settlement and cemetery at **Beckfoot**, located to the south-west of the main Wall, has been subject to significant coastal erosion over recent centuries, with archaeology buried under sand dunes being frequently exposed by coastal processes. **Birdoswald** is one of the best preserved of the 16 forts located along Hadrian's Wall, but, together with the nearby milecastle at Harrows Scar, is at critical risk to landslides instigated by fluvial erosion from the River Irthing to the south of the site. Finally, the modern day settlement of **Corbridge** marks the site of the most northerly town in the Roman Empire, but is subject to fluvial flood hazard from the River Tyne to the south.

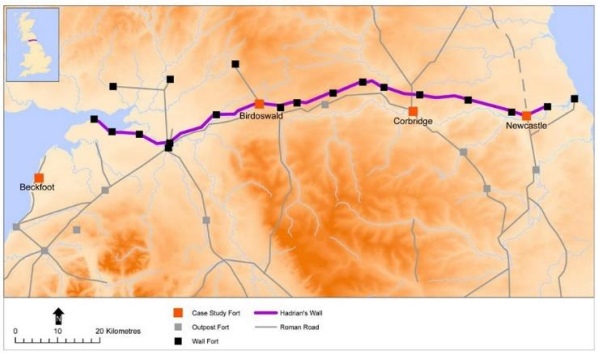

Figure 1: Location map of proposed study sites.

WP1: Review and data collation (academic supervisory lead: Mills)
Significant archive mining, new data collection and pre-processing has already taken place at each of the study sites as part of a separate EU-JPI coordinated, AHRC funded project, Cultural Heritage Through Time (CHT2). Amongst other datasets, this comprises historic mapping, archival aerial imagery, Unmanned Aerial Vehicle (UAV) sorties, airborne laser scanning (ALS) and geophysical surveys. In each of the three case studies this has resulted in a heterogeneous timeline of disparate data streams that require reconciliation to be meaningful. For example, at Beckfoot, HE archival aerial imagery from 1948 and 1991 has been digitised, augmented with ALS data from the UK's Environment Agency for 2009, 2010, 2013 and supplemented by 2016 UAV (comprising both RGB and CIR imagery – Figure 2), as well as geophysical surveys.

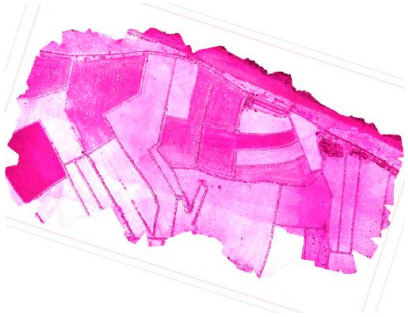

Figure 2: 2016 dense point cloud generated by SfM from UAV CIR imagery of Beckfoot.

Core data for the Birdoswald (e.g. Figure 3) and Corbridge study sites include similarly multifarious episodic surveys over analogous time spans. WP1 is therefore primarily a site reconnaissance, data familiarisation and literature critiquing exercise to establish the current state-of-the-art to inform subsequent WPs.

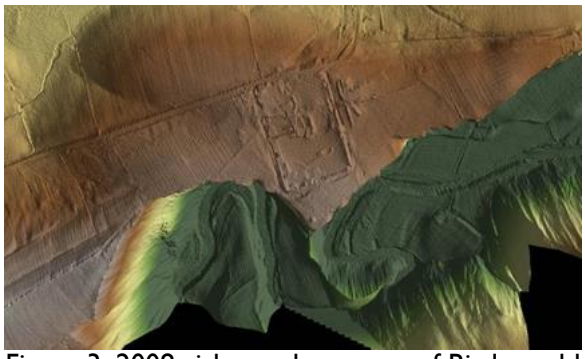

Figure 3: 2008 airborne laser scan of Birdoswald Roman Fort.

WP2: Time series extension and completion (academic supervisory lead: Mills)
Any data gaps identified in WP1 will be filled by data archive mining or field survey, as appropriate, in WP2. Historic extension may also be possible by exploiting recent and newly captured ground penetrating radar data at each site. 3D data for each individual epoch will be fused using the most appropriate data integration approaches, including surface matching and ICP routines, to ensure rigorous and seamless registration from epoch to epoch. This will result in spatially consistent 3D time series for subsequent landscape analysis in collaboration with EH/HE.

WP3: Predictive modelling (academic supervisory lead: Augarde)
WP3 will extend the temporal range prospectively into the future, by exploiting the compiled datasets to inform appropriate numerical models to predict coastal and fluvial evolution of the landscapes. Predictions will be undertaken using a variety of techniques, ranging from process-based numerical models to geometric approaches. Uncertainties in the various input data will be accounted for, including historic rates of change, rock strength, sediment content, etc. under different climate-change scenarios.

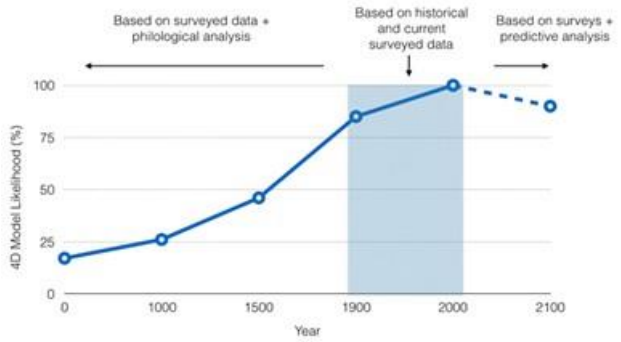

Figure 4: Time-dependent 3D analysis covered within the framework of our legacy through time (Gonzàles Aguilera et al., 2017).

WP4: Cultural heritage interpretation of findings (academic supervisory lead: Haynes)
Findings from WPs1 through 3 will provide new insight to support the study of the evolution phases of the Wall as a cultural heritage site, both to develop hypotheses about the past and to model future developments. Cultural heritage interpretation of results will run largely concurrently with other WPs, thereby helping to direct research into the most promising areas as they are revealed. In order to maximise the value of research outcomes by promoting their transfer to individuals and organisations, the project will also consider contemporary ways to best visualise, communicate and disseminate results, e.g. Figure 5.


Figure 5: 2016 Corbridge landscape generated from archive photography supplied by EH/HE.

Timeline

Year 1: Literature critique, data investigation; fieldwork for familiarisation of study sites and collection of additional datasets; EH/HE placement 1; national conference presentation.
Year 2: Collation, processing and fusion of datasets; modelling familiarisation; EH/HE placement 2; Refereed journal paper 1.
Year 3: Future predictive modelling; validation and cultural heritage interpretation of results; visualisation of findings; EH/HE placement 3.
Year 4 (6 months only): Thesis preparation; international conference presentation; refereed journal paper 2.

Training & Skills

The student will be primarily based in the Geomatics research group within the School of Civil Engineering and Geosciences at Newcastle University. Here the student will engage in regular research group meetings of the Newcastle Earth Observation Laboratory (NEO-Lab), developing research skills and broadening knowledge of on-going research in this field. The student's Personal Training Programme will ensure that they receive the necessary technical and research skills to support their development as an independent researcher. The student will also spend considerable time at the partner university of Durham, particularly during WP3 in Years 2 and 3.

Alongside this, the student will benefit from three one-month long periods where they will be immersed in the research environment of EH/HE (based out of York, but also sites in Newcastle and elsewhere), thereby complementing the support from the McCord Centre for Historic and Cultural Landscape based at Newcastle University's School of History, Classics and Archaeology. This will be highly beneficial in providing direct contact with experienced researchers working in the specialised field. Through this, the student will develop skills associated will managing a collaborative research programme.

References & Further Reading

Cultural Heritage Through Time (CHT2), 2016. http://cht2-project.eu/ [last accessed 13 Dec, 2016].

Gonzàles Aguilera, D., et al., 2017. 4D reconstruction and visualization of cultural heritage: analysing our legacy through time. *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences,* in press.

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Further Information

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