3D documenting and monitoring of coastal archaeological sites:

Challenges and lessons learnt

Introduction

Human activity, sea-level rise and other visible effects of climate change are threatening coastal and island territories on a global scale. In this context, hundreds of archaeological sites are currently threatened of destruction, implying that relevant -sometimes irreplaceable- scientific information is being lost. Detailed documentation and study of archaeological sites at risk of destruction is thus necessary. Among the different tools and initiatives implemented by cultural heritage specialists, researchers and managers, site erosion monitoring has been pointed out as one of the most suitable to tackle this problem (Ballard *et al.* 2022). Since 2013, we worked on the hypothesis that digital photogrammetry and terrestrial laser-scanning (TLS) techniques were the most suitable to monitor sites at risk, especially in contexts were erosion and weathering were very active, such as coastal and estuarine areas (López-Romero et al. 2014). These techniques are a rapid and effective way to digitally preserving, analysing and monitoring coastal archaeological sites, something that has been performed by our team in different areas of the European Atlantic façade. These techniques have proven to be relevant in the decision-planing process concerning the research and management of the sites. In this paper, we review the challenges and problems we encountered and we discuss some recent advances in 3D model fitting using circular statistics.

Materials and data

Stemming from the eSCOPES Marie Curie project n°328753 (Durham University, 2013-2015), several archaeological sites dating from the Neolithic to the Iron Age have been the object of detailed photographic and/or TLS recording. All of them are located close to the sea, within the intertidal area or at the top of cliffs subject to erosion (Lopez-Romero et al., 2014). Owing to their scientific interest and vulnerable situation, the Neolithic monuments of Coalen and Le Lomer (Brittany, Western France) and the Neolithic and Bronze Age monuments of the islet of Guidoiro Areoso (Galicia, Northwest Spain) have been given particular attention. While a qualitative analysis using a dedicated vulnerability evaluation form has systematically been used (Daire *et al.* 2011), the 3D modelling approach allows for a complementary spatial analysis of the changes operated on the sites.

Methodology

Extensive photographic documentation –in the range of several hundred photographs for each site – was undertaken every six months from September 2013 to September 2014. Two reflex cameras (Nikon D300 coupled with a GPS receiver and Canon EOS 700D) and a compact camera (Canon G10) were used for these purposes. Images were taken at the floor level (perpendicular and oblique to the sites and the surrounding area) and with the camera mounted on a pole (perpendicular to the floor). Topographic referencing was established with the help of a total station (Leica TCRP1203) and Differential Geographical Positioning System (DGPS, Leica GPS1200). One TLS recording of each site was also obtained. More recently, a new photographic campaign was completed for Le Lomer –in July 2023– and for Monument nº3 in Guidoiro Areoso –in April 2023–. As a result, 3D meshes, orthophotos and DEMs were obtained that allowed for short (6-month to 1-year intervals) and long (10-year intervals) erosion monitoring. While preliminary results were published concerning the methodology, the erosion processes and the integrity of the sites (e.g. López-Romero et al., 2016), we have recently produced a more comprehensive workflow for 2.5D analysis of the resulting DEMs that includes 3D model fitting through displacement vectors for increased accuracy (i.e. circular statistics; Mencía et al., Under Review).

Results & Conclusions

The results can be read in terms of short- and long-term erosion processes, and the different outputs can be used as tools for spatial, quantitative and qualitative analysis.

While TLS is a robust and precise documenting technique, the use of photogrammetry proved to be better adapted to the challenges and constraints of our work in islets and the coastal band (i.e. remote or steep locations, difficult to access with heavy equipment). However, data collection, storage and processing capacity must be planned in advance.

Also, while direct 3D analysis of the photogrammetric mesh can be performed (Fernández, Valle and Nóvoa, 2022; Lopez-Romero et al., 2017), 2.5D analysis of the resulting DEMs proved to be an excellent solution for our purposes; this allows for accurate, easy-to-read outputs that can be obtained through well-established and accessible GIS procedures (e.g., map algebra in open source software).

The use of circular statistics has been introduced to ensure whether all the georeferenced models considered have undergone any horizontal displacement that prevents a correct fit between them. We have not found references on the application of circular statistics related to adjusting the referencing of 3D models for coastal erosion, but this kind of analysis is already used in the study of stone pavement formation in deserts (Dietze and Kleber, 2012) or in modelling the seasonality of extreme coastal water levels (Veatch and Villarini, 2020).

Discussion

Considering the whole process and results, we believe the methodology is adapted to our initial objectives (erosion monitoring analysis, rapid assessments, etc.) and the results are satisfactory. We highlight the importance of a multidisciplinary team to solve the problems of working in such a specific environment.

Periodic monitoring of erosion processes has helped us understand changes at the microspatial scale while contributing to the decision-making process involving the different stakeholders and managers.

The work has also highlighted that there are protocols that must be more thoroughly addressed (e.g., greater attention in the field recording, avoiding footprints, algae deposits and other unwanted elements to be visible in the photographs).

Even though it has been implemented for the analysis of coastal cultural heritage (i.e., archaeological sites), this workflow is also useful for the analysis of other contexts and sites that are essential for our understanding of past human societies, such as coastal palaeoenvironmental archives that are subject to the same erosion processes (e.g.,Domínguez Almansa, Costa Casais and Riveiro Rodríguez, 2021).

Finally, the approach and results have also proven to be extremely useful in improving the dialogue between researchers, managers and the public, providing comprehensive 3D models and outputs that clearly show the effects and rhythm of erosion processes.

References

Daire M.Y., López-Romero E., Proust J.N., Regnauld H., Pian S. & Shi B. 2012: Coastal Changes and Cultural Heritage (1): Assessment of the Vulnerability of the Coastal Heritage in Western France. *Journal of Island and Coastal Archaeology* 7(2): 168-182.

Dietze, M. and Kleber, A. (2012). Contribution of lateral processes to stone pavement formation in deserts inferred from clast orientation patterns. *Geomorphology*, 139-140, pp. 172-187. https://doi.org/10.1016/j.geomorph.2011.10.015

Baillard, C., et al. 2022. *Cultural Heritage and Climate Change: New Challenges and Perspectives Perspectives for Research*. White Paper. JPI Cultural Heritage & JPI Climate,https://www.heritageresearch-hub.eu/app/uploads/2022/03/White-Paper-March-2022-def-14-mars.pdf

Domínguez-Almansa, A. et al. (2021). Cliffs with memory: historical and social teacher training via climatic and environmental transformations. In Gómez Carrasco, C. J. et al., eds. *Handbook of Research on Teacher Education in History and Geography*, Peter Lang GmbH, Internationaler Verlag der Wissenschaften, pp. 331-354. ISBN 978-3-631-81897-8

Fernández, A.F., Abad, P.V. and Nóvoa, A.A.R. (2022). 3D photogrammetry as a tool for studying erosive processes at a Roman coastal site: the case of the Roman fish-salting plant at Sobreira (Vigo, Spain). *Archaeological and Anthropological Sciences*, 14(2), 32.

López-Romero, E., et al. (2017). Recovering information from eroding and destroyed coastal archaeological sites: a crowdsourcing initiative in NW Iberia. In Dawson, T. et al, eds. *Public Archaeology and Climate Change*, Oxbow Books, Oxford & Philadelphia, pp. 72-80.

López-Romero, E. et al. (2016). Archaeology and coastal erosion: monitoring change through 3D digital techniques. In Kammerman H et al., eds. *The Three Dimensions of Archaeology. Proceedings of the VII UISPP World Congress (1-7 sept. 2014, Burgos, Spain)*. Volume 7/Sessions A4b and A12. Archaeopress Archaeology, pp. 89–97.

López-Romero, E. et al. (2014). The eSCOPES Project: preservation by record and monitoring at-risk coastal archaeological sites on the European Atlantic facade. *Antiquity*, 88(339). [online]. Available from: http://antiquity.ac.uk/projgall/lopez-romero339/ [Accessed May 16, 2024].

Mencía, J. et al. (under review). Comprehensive workflow for erosion monitoring of coastal archaeological sites by means of digital photogrammetry: an Iberian case study. *Digital Applications in Archaeology and Cultural Heritage*.

Veatch, W. and Villarini, G. (2020). Modeling the seasonality of extreme coastal water levels with mixtures of circular probability density functions. *Theoretical and Applied Climatology* 140(3), pp. 1199-1206. https://doi.org/10.1007/s00704-020-03143-1