Monitoring cultural heritage sites at risk using citizen engagement through crowdsourcing

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Abstract

One of the most significant consequences of climate change is the threat to cultural heritage sites. The TRIQUETRA project addresses the critical challenge posed by climate change to cultural heritage sites by applying a comprehensive risk assessment framework. This framework integrates traditional and advanced technologies, including remote sensing and laser-based spectroscopy, to quantify the severity of risks, monitor their progression, and inform effective mitigation strategies. Understanding the potential risks at site level is vital to ensure that appropriate adaptation and mitigation measures are put in place. Recent research underscores the compounded impacts of climate-induced geo-hazards, such as landslides and earthquakes, which threaten the physical integrity of monuments and the socio-economic systems they support. Citizen engagement is also an integral part of the TRIQUETRA project, creating a dynamic web and mobile platform where visitors actively participate in cultural heritage (CH) site monitoring. The TRIQUETRA application enables citizens and cultural heritage site visitors to play a vital role in capturing and uploading site photos, contributing therefore, valuable datasets that complement and enhance the existing 3D models. This process is aided by a backend system that can aid cultural site authorities to better monitor the site by having up to date imagery and reports from visitors. At the same time the TRIQUETRA Citizen Engagement Application creates an interactive and enhanced experience for cultural heritage site visitors through immersive Augmented Reality (AR) experiences. The application provides additional information through an AR experience where user can learn more about critical features at risk, such as areas affected by climate change or structural vulnerabilities, fostering awareness and promoting preservation efforts. The methodology was applied to the Choirokoitia site in Cyprus, which is listed as a UNESCO World Heritage Site as it is one of the best-preserved Neolithic sites in the Mediterranean. The Choirokoitia site will examine the potential risk of rockfall, as the topology of the site is vulnerable to movements as a result of extreme climate change as well as of daily/seasonal stressing actions. By integrating advanced technologies and community-driven monitoring, TRIQUETRA ensures a holistic approach to safeguarding cultural heritage. The project creates a replicable framework that enhances risk assessment and promotes active participation in preservation efforts, offering scalable benefits for cultural heritage sites worldwide.

1. Introduction

The increasing impact of climate change on cultural heritage sites presents a global challenge for preservation and management efforts worldwide. Cultural heritage sites represent invaluable historical and cultural records. Rising temperatures, changing precipitation patterns, and increased frequency of extreme weather events accelerate material degradation, geohazards, and structural vulnerabilities in ancient monuments and archaeological sites. Traditional monitoring approaches, such as on-site inspections and terrestrial photogrammetry, are often labor-intensive, expensive, and limited in spatial and temporal coverage. There is an urgent need for more innovative, cost-effective, and scalable solutions that enable continuous monitoring and timely intervention to mitigate risks (Themistocleous, 2023; Themistocleous et al, 2023). Research indicates that advanced technologies using Earth observation and remote sensing techniques can be used to monitor cultural heritage risks (Themistocleous, 2023; Themistocleous & Danezis, 2018; Margottini et al, 2015; Novellino et al, 2018; Margottini et al, 2018; Gikas 2012; Themistocleous 2017; Themistocleous et al, 2021). The integration of citizen engagement through crowdsourcing offers a scalable and cost-effective solution for real-time monitoring and preservation.

In order to gather data to assess and monitor the impact of climate change on the site, different technologies were utilized. The major issue regarding climate change at the site is the emergence of rockfalls, which is more pronounced during the winter months, especially when very hot summers are followed by heavy flash rainfall (Themistocleous & Abate, 2024; Valagussa et al, 2018). Rockfall is a potential occurrence, since the geology of the site includes large rocks that are loose at high elevation (Figure 1), which are vulnerable to movement as a result of flash rainfall during winter. The frequency of rockfall events every year has alerted the stakeholders to develop methodologies for monitoring the site to identify the problem and provide mitigation techniques to minimize the extent of the hazard and provide more secure access to the site (Themistocleous, 2023; Themistocleous et al, 2018).

Figure 1. Rock formations at the Choirokoitia site

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The TRIQUETRA project addresses these challenges through an integrated approach that combines remote sensing technologies, crowdsourcing, and immersive augmented and virtual reality experiences to enhance cultural heritage monitoring and preservation (Anastasiou et al, 2024). By integrating Synthetic Aperture Radar (SAR) interferometry, UAV-based photogrammetry, deep learning models for image processing, and real-time data collection via citizen engagement, TRIQUETRA offers an innovative framework for near real-time risk detection and dynamic site conservation strategies. The TRIQUETRA mobile application further extends this capability by engaging visitors in data collection, allowing them to contribute geotagged photographs and relevant environmental observations. These crowdsourced datasets are processed through a 3D modeling pipeline, which refines digital site representations and identifies early warning signs of changes in the site.

This study focuses on the systematic monitoring of such geohazards, specifically those of ground deformation and rock falls that are induced due to climate change, to facilitate the early recognition of potential risks and to enable effective conservation monitoring and planning. Since the site is vulnerable to movements due to extreme climate change, the risk of rockfall poses a potential danger to tourist safety. By integrating augmented reality (AR) and virtual reality (VR) experiences, TRIQUETRA enhances public engagement and awareness by offering visitors an immersive way to explore historical site reconstructions, climate change projections, and interactive risk visualizations (Anastasiou et al, 2024).

2. The Choirokitia Site

The Neolithic settlement of Choirokoitia (Figure 2), located in Cyprus, is recognized as one of the most well-preserved prehistoric sites in the Mediterranean region. Dating back to the 9th millennium BCE, it represents a pivotal period in human civilization, marking the transition from nomadic hunter-gatherer societies to settled agrarian communities. The site's circular dwellings, complex social structures, and evidence of early domesticated agriculture provide an unparalleled window into the Aceramic Neolithic period. As a UNESCO World Heritage site, Choirokoitia is of global archaeological significance, requiring rigorous conservation efforts to ensure its preservation. However, its geographical and geological context presents substantial conservation challenges due to climate-induced environmental changes.

Figure 2. Choirokoitia site

Choirokoitia is situated within the Maroni River valley, near the Troodos Mountain range, where it is exposed to steep, sedimentary rock formations prone to weathering, erosion, and slope instability. The region experiences long, dry summers with extreme heatwaves, followed by intense flash rainfall events during winter, exacerbating freeze-thaw cycles that contribute to rockfalls and structural degradation.

The primary climate-related risks to the site include *rockfalls*, where large, loose boulders at higher elevations become dislodged due to seasonal changes in moisture content and temperature; *ground deformation*, where soil contraction and expansion due to prolonged droughts or heavy rains lead to surface instabilities, and *erosion*, where intense runoff from seasonal rainstorms accelerates surface degradation. Given these vulnerabilities, continuous monitoring and predictive risk assessment are essential to proactively mitigate potential damage.

Recognizing the complexity of these threats, the TRIQUETRA project emphasizes an integrated monitoring system, by linking satellite Earth observation data, UAV data and in-situ measurements to capture both large-scale environmental shifts and localized physical and environmental changes (Themistocleous et al, 2023; Anastasiou et al, 2024). The project provides a multi-disciplinary approach that integrates remote sensing and monitoring through crowdsourcing to establish an effective early-warning system for site conservation.

3. Methodology

The crowdsourcing component of the TRIQUETRA project is designed to engage tourists, visitors and local communities in the continuous monitoring and preservation of cultural heritage sites. By leveraging a mobile and web-based application, the system enables users to contribute geo-tagged images, descriptive site condition reports, and environmental observations that supplement traditional monitoring methods.

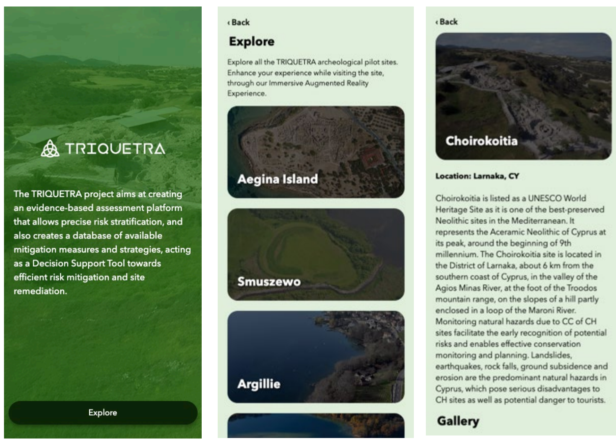

Figure 3. Screenshots from the Triquetra Application

The TRIQUETRA application (Figure 3) serves as a key tool in engaging visitors and facilitating the crowdsourcing of data to support cultural heritage monitoring. Designed as an intuitive, user-friendly web platform, the application provides an interactive experience for cultural heritage visitors while also functioning as a valuable data collection tool for heritage authorities.

The TRIQUETRA mobile and web application functions as the primary interface for crowdsourced data collection. It is designed with an intuitive and accessible user interface to encourage visitor participation while ensuring the accuracy and reliability of the gathered information. The application provides its users with initial information about the cultural heritage site they are visiting, including text-based content, image galleries, and interactive 3D models. These resources allow visitors to familiarize themselves with the site's historical and architectural significance before engaging with the more advanced AR, 3D visualization features and crowdsourcing capabilities. Through the application, users can capture and upload photos of the sites, which are then archived in a central image repository. This crowdsourced imagery is crucial in identifying early signs of environmental changes that could threaten the integrity of the heritage sites. Additionally, a built-in questionnaire and feedback system allows visitors to contribute their perspectives on the site’s condition, helping authorities gather qualitative data that complements the crowdsourced imagery. By integrating this two-way interaction between visitors and stakeholders the TRIQUETRA framework employs collective intelligence to continuously enhance conservation strategies.

3.1 Implementation Technologies

The application and backend platform are built on a robust technological stack that ensures scalability, reliability, and ease of use. The backend system is developed using Python and the Django web framework, providing a secure and efficient server-side framework for handling user data, image uploads, and 3D model updates. The custom-built administration panel allows cultural heritage experts to manage site data and monitor user contributions. The frontend is developed using HTML5, CSS3, and JavaScript, ensuring a lightweight and responsive interface that is optimized for both web and mobile users. The interface is designed to be intuitive, allowing visitors to seamlessly interact with 3D models, augmented reality features, and site information.

The 3D modeling functionality is built using Metashape and Metashape Python API, which allows the generation and continuous refinement of 3D models based on crowdsourced imagery (Agisoft 2023). Visitors upload images of heritage sites Figure 4), which are processed in order to update the existing 3D digital volumetric representation models, ensuring that site data remains current and accurate. For visualization of point cloud data, the platform integrates Potree, a web-based point cloud viewer that enables users to explore highly detailed 3D scans of cultural heritage sites.

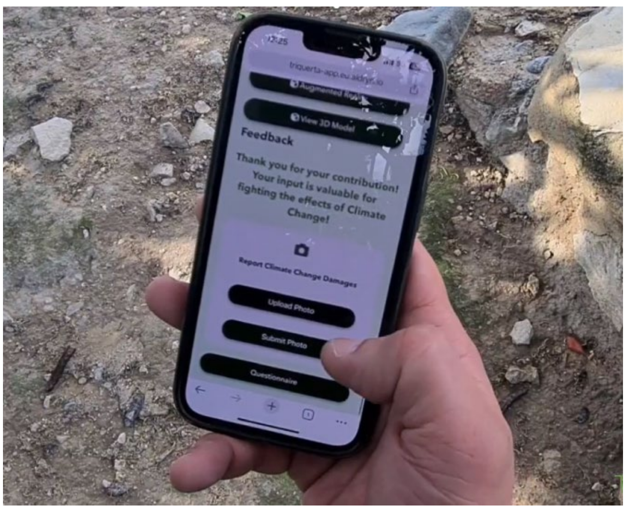

Figure 4. Crowdsourcing web application

Once the visitor-submitted images have been aligned within the Metashape environment, the system employs a dense reconstruction process to refine existing point clouds. As part of this workflow, an optimization step is applied to reduce alignment errors and ensure spatial coherence with UAV-collected data. Such technologies create a comprehensive and interactive digital experience that supports both public engagement and heritage site monitoring. The combination of crowdsourced data and advanced digital modeling ensures a sustainable and scalable approach to preserving cultural heritage sites in the face of climate change and environmental threats.

Additionally, to enhance accessibility and scalability, the application is implemented as a web-based mobile-optimized application rather than requiring users to download a dedicated mobile application. This approach allows for seamless access across devices without installation barriers, making it more inclusive. Users can simply scan a QR code at the site and access all functionalities. Furthermore, the web implementation is optimized to consume less data, ensuring that participation remains feasible even in areas with restricted internet bandwidth. The AR functionality is powered by AR.js and the A-Frame framework, enabling users to overlay digital information onto the real-world environment. Through AR.js, visitors can access historical reconstructions, interactive site elements, and informative overlays that enhance their understanding of cultural heritage sites.

3.2 Enhancing 3D Models through Crowdsourcing

The process of enhancing 3D models using crowdsourced images is a key component of the TRIQUETRA project, aiming to keep up-to-date and accurate representations of heritage sites. This process is fully programmatic and is carried out using the MetaShape Python API, allowing automated refinement of existing 3D models based on new visitor-submitted images. The workflow is hosted on a dedicated web server to ensure both efficiency and scalability.

The automated pipeline makes use of the Python Metashape API capabilities and executes all necessary steps automatically. Whenever newly submitted crowdsourced images are imported into an existing Metashape project, which contains the 3D model, an alignment process is executed to match them with the existing 3D structure. If possible, an optimization step is carried out to refine the photo alignment, improving accuracy and reducing errors. If the new photos can be matched, the system rebuilds the dense cloud and/or mesh, updating the model with the latest visual data. Finally, the enhanced 3D model is saved and exported, along with any required new point cloud data, thus providing stakeholders with an updated version of the site’s digital representation.

3.3 Augmented and Virtual Reality Enhancements

Beyond the crowdsourcing capabilities and the visual and interactive features, the application supports active citizen participation through real-time data contributions. TRIQUETRA enriches users’ experiences through immersive AR features. By blending the physical realm with digital overlays, visitors can examine historic reconstructions or learn about less visible aspects of site vulnerability. An interactive 3D model viewer allows individuals to inspect high-resolution, annotated reconstructions of specific artifacts or structural elements. These annotations can include textual or audiovisual commentary about historical contexts, building materials, or engineering techniques employed by ancient societies. By linking compelling visual content with accessible information, the application fosters a deeper emotional and intellectual connection between audiences and heritage sites.

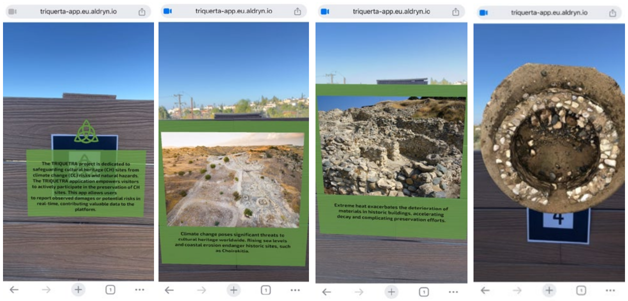

Figure 5. Screenshots of the AR functionality

The AR experience allows visitors to explore cultural heritage sites in an enriched way. Through the AR camera view, users can view areas (curated and selected by the authorities) that may be threatened by climate changes, thereby galvanizing collective understanding and promoting conscientious behaviour among visitors and tourists. Through AR overlays and other multimedia content, users can view historical reconstructions of sites, examine detailed structural insights, and understand potential climate risks affecting the monuments. The AR implementation and mechanisms in Figure 5 highlight four screenshots of the application where multimedia content (text images and 3D models) is displayed through the Application's Camera View.

The Triquetra Application also includes an interactive 3D model viewer through AR, enabling users to navigate high-resolution digital representations of specific aspects and features of the heritage sites. These 3D models can be annotated with relevant historical and structural information, offering an educational layer to the experience. The AR experience helps bridge the gap between past and present, making climate challenges more visible while enhancing educational value.

For more immersive tours, VR modules (Figure 6) allow visitors to virtually "walk through" reconstructed versions of Choirokoitia. This feature is especially beneficial for areas of the site that are physically restricted due to ongoing excavations or conservation work. By providing engaging educational materials and interactive layers within these virtual environments, TRIQUETRA fosters a deeper emotional and intellectual connection to the site, which in turn can encourage more proactive conservation advocacy among visitors.

Figure 6. Screenshots of the VR functionality

3.4 Overall system Architecture, data validation and accuracy assessment

The technological framework behind TRIQUETRA is designed for modularity, scalability, and cross-platform compatibility. A Python and Django-based backend handles user authentication, data collection, and image storage. A modular architecture ensures that tasks such as photo alignment, 3D model generation, and AR/VR data management can be horizontally scaled as user traffic and data volume grow. The frontend is developed using HTML5, CSS3, and JavaScript, ensuring broad accessibility on both desktop browsers and mobile devices without the need for an application download.

Data is transferred from visitors' smartphones or tablets into a centralized repository, where it is immediately queued for validation and processing. Once the data has been cleared by automated and manual checks, it is fed into the Metashape-based photogrammetry pipeline, which updates the site's 3D model. The final output can then be accessed by both site authorities, through an administration panel with detailed visual analytics, and by the public, through AR and VR enhanced explorations. This end-to-end workflow ensures a continuous feedback loop that embraces constant model refinement and transparent, user-friendly interaction with heritage content.

Maintaining data quality is crucial to the efficacy of any monitoring system that relies on crowdsourced inputs. TRIQUETRA implements a multi-tiered validation framework designed to filter out erroneous or irrelevant submissions before they feed into the 3D modeling pipeline. At the most basic level, automated scripts monitor metadata such as GPS coordinates and timestamps to confirm that the submitted imagery corresponds to the target site and relevant timeframe. Images failing to meet these criteria are flagged for manual review.

A subsequent stage of validation could involve algorithmic checks on image sharpness and content relevance. An image classifier could evaluate each photo to detect motion blur, off-topic scenes, or images that do not show archaeological features. Photos passing this filter will be subjected to a more detailed inspection, where they would be compared against a reference 3D model using feature extraction and matching. Successful alignment will indicate that the new images can be integrated into the existing 3D reconstruction workflow.

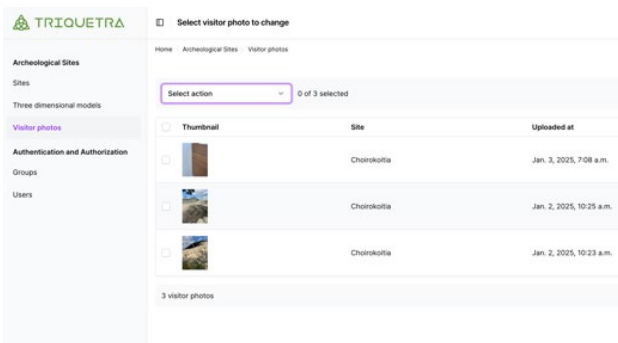

Figure 7. Screenshots of the AR functionality

Authorities at Choirokoitia and collaborating researchers can perform final checks through the project's administrative panel, which displays both raw user-submitted images and their alignment results within the site model. This human-in-the-loop mechanism allows for nuanced judgment on borderline cases, such as partially obscured structures, while also facilitating the discovery of rare, unexpected changes. In tandem, automated and manual validation steps help ensure that the digital twin of the site remains accurate and that any anomalies detected are meaningful indicators of potential risks. This panel (Figure 7) provides access to all uploaded images for each heritage site, enabling administrators to track changes over time and assess potential structural or environmental risks. The centralized repository of visitor-contributed data allows authorities to analyse historical photographs and identify emerging issues that may require intervention.

Ensuring the accuracy and reliability of crowdsourced data is critical for its effective use in decision-making and monitoring. Currently authorities at Choitokoitia are able to conduct manual checks and verification of the submitted user photos. However, several techniques are being evaluated to optimise this process by adding automatic data validation steps such as automatically detecting blurry or irrelevant photos using AI and Machine Learning.

The TRIQUETRA platform is designed to support multiple cultural heritage sites, ensuring its scalability beyond the initial pilot locations. Currently, the system includes information about the selected TRIQUETRA pilot sites, but it has been built using dynamic and modular concepts that allow for flexibility and expansion. New cultural heritage sites can be added effortlessly by integrating site-specific data, including images, metadata, and 3D models. The system architecture enables the straightforward addition of new sites without requiring significant modifications to the platform, ensuring that it can scale to support a broad range of heritage locations globally.

Future iterations of the TRIQUETRA framework will explore integrating sensors for temperature, humidity, and seismic activity, further expanding the dataset used for predictive analytics and early warnings of potential environmental changes.

4. Results and Discussion

The results presented in this study validate TRIQUETRA’s effectiveness as a replicable strategy for addressing the growing threat of climate change to humanity’s shared past. By uniting advanced technological solutions with strong community engagement and clear policy alignment, TRIQUETRA points the way toward a more resilient paradigm for heritage conservation in the 21st century.

Preliminary data collected from the Choirokoitia site indicate that rockfall risks are significantly influenced by seasonal climatic patterns, particularly the interplay between prolonged heatwaves and subsequent flash rainfall events. Through crowdsourced imagery, site managers have been able to isolate specific problem areas where protective netting or structural reinforcements may be required, demonstrating the practical value of real-time monitoring.

From a policy standpoint, TRIQUETRA seeks to align with global and national frameworks, such as UNESCO’s World Heritage and Climate Change initiatives, by offering a standardized methodology that can be adapted to different archaeological contexts. Developing open data standards and collaborative repositories is seen as a long-term goal to foster data sharing and collective learning across multiple heritage sites. In this manner, TRIQUETRA not only contributes technological solutions but also promotes a culture of shared responsibility and knowledge exchange in the conservation community.

While crowdsourcing presents unique advantages in terms of scalability and inclusivity, it also introduces ethical and logistical challenges. TRIQUETRA employs best practices to safeguard user privacy by anonymizing personal data and geolocations to the extent possible without compromising scientific validity. Additionally, the platform includes consent protocols that clarify how submitted images and feedback may be used for both research and heritage management.

Logistically, ensuring widespread adoption of the mobile platform requires reliable on-site internet access, user-friendly interface design, and informative signage to explain the crowdsourcing process. In regions with intermittent connectivity, users can capture photos using their device's camera app and upload them later through our app once a stable internet connection is available. This approach ensures seamless functionality while accommodating real-world accessibility constraints.

Moreover, continuous engagement with tourist operators, stakeholders and local communities, through outreach programs and educational materials, can significantly boost participation rates and the quality of user-contributed data, further solidifying the crowdsourcing model as a robust monitoring tool.

5. Conclusion

The Choirokoitia case study underscores the feasibility and impact of leveraging advanced remote sensing, AI-driven crowdsourcing, and immersive AR/VR for cultural heritage preservation. By integrating multi-source data streams into a holistic framework, TRIQUETRA offers continuous monitoring, timely detection of structural and environmental risks, and a participatory mechanism that actively involves the public in safeguarding archaeological sites.

The crowdsourcing methodology employed represents an innovative approach to enhancing cultural heritage monitoring through citizen driven data collection and engagement. By integrating AI-driven image validation, real-time 3D model enhancements, and automated risk detection, the system ensures that crowdsourced data maintains high scientific validity while significantly increasing the spatial and temporal frequency of site assessments. The inclusion of administrative dashboards and interactive visualization tools further empowers heritage site authorities to make informed, data-driven conservation decisions.

The approach delivers several key advantages, including higher temporal resolution of data, broader spatial coverage, and the capacity to engage both experts and non-experts in a shared endeavour. Beyond Choirokoitia, the system’s modular design and reliance on widely available web technologies render it adaptable to diverse cultural heritage contexts worldwide. Future plans include refining predictive modeling capabilities, implementing data integrity solutions, and scaling policy integration efforts to achieve broader institutional adoption.

With a replicable framework that can be applied to diverse heritage sites worldwide, the TRIQUETRA crowdsourcing model stands as a scalable, sustainable, and community-driven approach to cultural heritage preservation in the face of climate change and environmental degradation.

By bridging technological innovation, policy collaboration, and public participation, TRIQUETRA not only enriches our understanding of cultural heritage vulnerabilities but also empowers local and international stakeholders to collaboratively protect our shared past.

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References

Agisoft, 2023. Metashape Python API Documentation. Retrieved from https://www.agisoft.com/

Anastasiou, A., Ioannidis, C., Spyrakos, C., Verykokou, S., Istrati, D., Sarris, A., Martino, S., Themistocleous, K., Hadjimitsis, D., Feidas, H. and Zanis, P., 2024. TRIQUETRA project: The Mediterranean sites (*No. Plinius18-48). Copernicus Meetings*.

Gikas, V., 2012. 3D Terrestrial Laser Scanning for Geometry Documentation and Construction Management of Highway Tunnels during Excavation, *SENSORS*, 12, 11249-11270.

Margottini, C., Antidze, N., Corominas, J., Crosta, G. B., Frattini, P., Gigli, G., Giordan, D., Iwasaky, I. ,Lollino, G., Manconi, A.,Marinos, P., Scavia, C., Sonnessa, A., Spizzichino, D., Vacheishvili N., 2015. Landslide hazard, monitoring and conservation strategy for the safeguard of Vardzia Byzantine monastery complex. *Landslides*, 12(1), pp. 193–204. DOI: 10.1007/s10346-014-0548-z

Margottini C., Spizzichino D., Leoni G., Bee E.J., Crosta G.B., Frattini P., Themistocleous K. and Fernandez Merodo J.A., 2018. Satellite Monitoring Applied to Natural Hazards and Cultural Heritage: The PROTHEGO Project. *Sixth International Conferenceon Remote Sensing and Geo-information of Environment*, 26-29 March, 2018, Paphos, Cyprus.

Novellino A., Harrison A., Bee E., Wang L., Hobbs P., Margottini C., Themistocleous K., Crosta G.B., and Fernandez Merodo J.A., 2018. Characterising and modelling geohazard susceptibility in the UNESCO World Heritage Site of the Derwent Valley Mills (UK). Geophysical Research Abstracts, 20, EGU2018-13316-1, 2018, *EGU General Assembly 2018*, Vienna, 8–13 April 2018.

Themistocleous K. (2017) The Use of UAVs To Monitor Archeological Sites: The Case Study of Choirokoitia within the PROTHEGOProject. *Fifth International Conference on Remote Sensing and Geo-information of Environment*, 20-23 March, 2017, Paphos, Cyprus
Potree, Potree Source code and Github page. Retrieved from https://github.com/potree/potree?tab=readme-ov-file

Themistocleous, K., (2023). Monitoring Cultural Heritage Sites Affected by Geohazards in Cyprus Using Earth Observation. In *Sustainable Conservation of UNESCO and Other Heritage Sites Through Proactive Geosciences* (pp. 359-377). Cham: Springer International Publishing.

Themistocleous, K. and Abate, D.: The Use of Digital Twins for the Management of Cultural Heritage Sites, *EGU General Assembly 2024*, Vienna, Austria, 14–19 Apr 2024, EGU24-20549, https://doi.org/10.5194/egusphere-egu24-20549, 2024.

Themistocleous K., Danezis C. (2018) Monitoring cultural heritage sites affected by geohazards, *Proc. SPIE 10790, Earth Resources and Environmental Remote Sensing/GIS Applications IX*, 1079009 (9 October 2018); doi: 10.1117/12.2325455; https://doi.org/10.1117/12.2325455

Themistocleous, K., Danezis, C., Gikas, V. (2021). Monitoring ground deformation of cultural heritage sites using SAR and geodetic techniques: the case study of Choirokoitia, Cyprus. *Appl Geomat* 13, 37–49. https://doi.org/10.1007/s12518-020-00329-0

Themistocleous, K., Fotiou, K., Tzouvaras, M., 2023. Monitoring natural and geo- hazards at cultural heritage sites using Earth observation: the case study of Choirokoitia, Cyprus, *EGU General Assembly 2023*, Vienna, Austria, 23–28 Apr 2023, EGU23-16436, https://doi.org/10.5194/egusphere-egu23-16436.

Themistocleous K., Hadjimitsis D.G., Michaelides S., Spizzichino D., J., Crosta G.B., Fernandez Merodo J.A. & Bee E., 2018. Best Practices For Monitoring, Mitigation and Preservation of Cultural Heritage Sites Affected By Geo-Hazards. *Geophysical Research Abstracts Vol. 20*, EGU2018-18220-1, 2018 EGU General Assembly 2018, Vienna, 8–13 April 2018.

Valagussa A., Frattini P., Crosta G., Themistocleous K., Margottini C., Spizzichino D., Bee E., Fernandez-Merodo J.A., 2018. 3D rockfall modelling in the Choirokoitia UNESCO World Heritage site. *Geophysical Research Abstracts Vol. 20*, EGU2018-15358, 2018 EGU General Assembly 2018, Vienna, 8–13 April 2018.