Connecting

THE RESEARCH PROMOTION FOUNDATION PROGRAMMES FOR RESEARCH, TECHNOLOGICAL DEVELOPMENT AND INNOVATION "RESTART 2016 – 2020"	
PILLAR	**I. SMART GROWTH**
PROGRAMME	**RESEARCH INFRASTRUCTURES/SMALL SCALE INFRASTRUCTURES**
RPF PROPOSAL NUMBER	**SMALL SCALE INFRASTRUCTURES/1222/0062**
PROJECT FULL TITLE	**Research and Innovation Knowledge Centre for Engineering in Heritage**
PROJECT ACRONYM	**CONNECTING**
Work Package	**WP2 – Dissemination and Exploitation Activities**
Deliverable	**D9 – 2 International Conference papers**

ACKNOWLEDGEMENT: This project has received funding from the European Regional Development Fund and the Republic of Cyprus through the Research and Innovation Foundation of Cyprus under contract SMALL SCALE INFRASTRUCTURES/1222/0062. More info regarding the project you can find here: https://connecting-infra.eu/

Dissemination Level		
PU	Public	✔
CO	Confidential, only for members of the consortium (including the Agency Services)	

Document Sign-off		
Status of the document	**Organization**	**Date**
Drafted	CUT	20/04/2026
Reviewed	CONNECTING CONSORTIUM	23/05/2026
Approved	CONNECTING CONSORTIUM	27/05/2026
Submitted	CUT	31/05/2026

OWNERSHIP AND USE				
Work Package: 2 – Dissemination and Exploitation Activities				
Deliverable D9: 2 International Conference papers				
Sections to be protected	**Description**	**Owner**	**Access Rights**	
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N/A	Public material	CONNECTING consortium	N/A	- Reuse - Acknowledgement

Introducing the CONNECTING Alliance:

A Small-Scale Infrastructure Project for Supporting Research and Innovation for Heritage

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Keywords: *Cultural Heritage, Documentation, Remote Sensors, UAV, Earth Observation, Underwater Object Detection.*

This paper introduces the “Research and Innovation Knowledge Centre for Engineering in Heritage”, in short CONNECTING [1], a recently funded project by the European Regional Development Fund and the Republic of Cyprus. CONNECTING envisions to establish a knowledge center for cultural heritage sites and monuments, through the acquisition of advanced sensors and platforms, such as vertical takeoff and landing drones, RGB, multi- and hyperspectral cameras, LiDAR systems, terrestrial laser scanner, soil moisture, ultrasonic, inclinometers, wireless strain sensors, and multibeam echosounder.

Project CONNECTING aspires to serve as a research hub for the consortium partners and supporters. The consortium consists of four partners, namely the Cyprus University of Technology, Infralabs Ltd, University of Cyprus and Department of Antiquities of Cyprus who are working together to deliver the two innovative demonstration activities outlined in the project. The project will provide best practices learned from experience in the form of a report from the leading academic institution with the support of the national stakeholder responsible for heritage management in Cyprus (Department of Antiquities).

Advanced remote sensing techniques and portable sensors will be employed to capture the geometry and form of complex monuments and sites using photogrammetric techniques and Structure from Motion (SfM) analysis. Low-altitude sensors mounted on drones will capture a site with high accuracy. At the same time, in-situ laser scanners and close-range photogrammetry will document architectural details, materials, and the state of preservation, depending on the case. The resulting comprehensive 3D point cloud, upon further processing will yield structured and georeferenced 3D models. Finally, a multibeam echosounder will be used to support underwater archaeological surveys.

Acknowledgments: This project has received funding from the European Regional Development Fund and the Republic of Cyprus through the Research and Innovation Foundation of Cyprus under contract SMALL SCALE INFRASTRUCTURES/1222/0062.

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ARCHAEOLOGICAL SURFACE CERAMICS DETECTION USING LOW ALTITUDE IMAGES BASED ON WEAK LEARNERS

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ABSTRACT

Over the past decade, remote sensing sensors and their products have been increasingly utilized for archaeological science and cultural heritage studies. In our study, we explored the application of several supervised machine learning classifiers using red-green-blue (RGB) and multispectral high-resolution drone imagery to evaluate their performance towards semi-automatic surface ceramic detection. The results indicate that using low-altitude remote sensing sensors and advanced image-processing techniques can be incredibly innovative in archaeological research. However, our study also revealed existing research limitations in detecting surface ceramics, which significantly impact the detection accuracy. Therefore, detecting surface ceramics using RGB or multi-spectral drone imagery should be reconsidered as an 'imbalanced data distribution' problem. A new and robust methodology needed to be developed to address this "accuracy paradox" of imbalanced data samples and optimise archaeological surface ceramic detection. Our study aimed to fill a gap in the literature by blending AI methodologies for non-uniformly distributed classes.

Index Terms— Archaeology, Machine Learning (ML), Object detection, Classification, Earth Observation

1. INTRODUCTION

In recent years, remote sensing science has been progressively applied to support archaeological research [1,2]. Technological innovation and improvements of space-based sensors, in terms of their spatial and spectral resolution, and the adoption of open access and free distribution of satellite datasets (see Landsat and Sentinel products), have motivated the further use of space-based remote sensing applications [3]. In addition, the democratization of low-altitude systems, with drones at relevant low costs, has been widely adopted in the last decade in archaeological research, mainly for documentation purposes [4]. At the same time, archaeological computational approaches have shifted from desktop-based applications to cloud-based approaches blended with advanced AI algorithms [5]. As these changes have taken place in a relevant short period (a decade), one can argue that we are still in the beginning of a new era of so-called “remote sensing archaeology”.

Orengo and Garcia-Molsosa in 2019 [5] demonstrated the great potential using the Google Earth Engine big data cloud platform, for detecting archaeological potsherds based on the acquisition of high-resolution UAVs red, green, blue (RGB) images and the application of random forest classification. Their work is pioneer as this was the very first example aiming to advance low altitude technologies with remote sensing methodologies for archaeological surface detection. Their work was based on a supervised Random Forest classification using training samples from the high-resolution orthophoto of their area of interest. Recently, in 2021, the authors also improved their previous work by developing a novel framework for detecting surface pottery, showing that low-altitude remote sensing sensors (e.g., Unmanned Aerial Vehicles, UAVs) can provide significant outcomes.

2. CASE STUDY

The purpose of this research is to explore how Artificial Intelligence (AI) algorithms can be used to classify and detect archaeological surface ceramics using low-altitude sensor cameras and how an interdisciplinary approach between Remote Sensing and Artificial intelligence can overcome the 'accuracy paradox' phenomenon of working with imbalanced remote sensing data.

When we classify data, we usually consider a model with higher accuracy the best. However, this may not be the case when dealing with imbalanced data. Imbalanced data sets have a disproportionate number of samples in different classes. When we use standard classifier learning algorithms to classify data with imbalanced class distribution, their performance can be greatly affected.

Various factors can affect the modeling of minority classes, including small sample size, separability, and the presence of sub-concepts within a class. To tackle this problem, this study employs an interdisciplinary methodology combining Remote Sensing with Artificial Intelligence. The goal is to address the paradoxical effect caused by these factors.

3. METHODOLOGY

This research methodology involves using Artificial Intelligence algorithms to classify archaeological ceramic surfaces. The images are captured through low-altitude sensor cameras. We used two drones to acquire drone-based images of the selected area of interest. Two flight campaigns were performed using the DJI Phantom 4 Pro system (spectral bands: Blue (B): 468 nm ± 47 nm; Green (G): 532 nm ± 58 nm; Red (R): 594 nm ± 32.5 nm), and the DJI P4 Multi-spectral system (spectral bands: Blue (B): 450 nm ± 16 nm; Green (G): 560 nm ± 16 nm; Red (R): 650 nm ± 16 nm; Red edge (RE): 730 nm ± 16 nm and Near-infrared (NIR): 840 nm ± 26 nm). The process is illustrated in diagram 1 below.

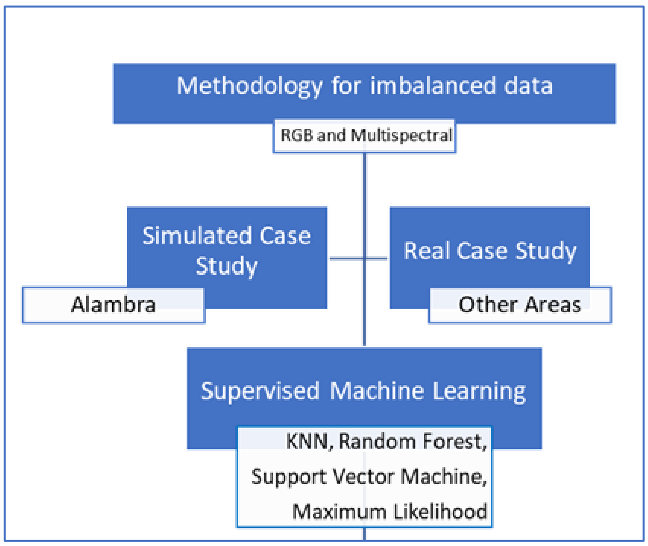

Diagram 1: Research methodology.

ArcGIS Pro software's Image Analyst tools were used for computational processing. One of the main challenges faced was dealing with imbalanced remote sensing data. To overcome this, the Training Samples Manager in the Classification Tools was used to create a training model comprising of three classes - 'ceramics' (class 1), 'soil' (class 2), and 'crops' (class 3). To create the initial training data, polygons were drawn on top of visible ceramic fragments, bare soil, and crops. The values of the pixels delimited by the polygons in each composite band were assigned to each class. Finally, four supervised classifiers - K-Nearest Neighbour (KNN), Random Forest (RF), Support Vector Machine (SVM), and the Maximum Likelihood algorithm were applied to the data. The maximum number of samples per class was set to 500 for the SVM, RF, and KNN classifiers, as this was deemed sufficient to ensure optimal results. The first step in the process was to classify the composite images using a trained classifier. Then, the classification was compared to the orthomosaic to assess its accuracy. To do this, randomly sampled points were created for post-classification accuracy assessment. The Accuracy Assessment Points tool from the Image Analyst tools evaluated all classification results. Randomly distributed samples were created for each class with an equal number of samples and then compared with the classification results. Based on the confusion matrix per classifier, the user's and producer's accuracy for each class and the overall kappa index were calculated. This procedure was implemented for RGB and multispectral drone images, and all results were extracted and evaluated on a local computer. Many standard classifier learning algorithms assume an equal distribution of classes and misclassification costs. However, these algorithms may not perform well when used on imbalanced data sets. An imbalanced data set is one where the class proportions are skewed, where the majority class has a larger proportion of samples than the minority class (in this case, archaeological surface ceramics).

In data analysis, it is often observed that the distribution of data in an imbalanced dataset is heavily skewed towards one class. This can pose a significant challenge while modelling minority classes, such as ceramics. Several factors can influence the modelling of such classes, including small sample sizes, separability, and the presence of sub-concepts. Small sample sizes lead to a lack of representation of the minority class, making it difficult to train a model that can accurately classify them. Separability refers to the degree to which the minority class is distinct from the majority class. If the minority class is poorly separable from the majority class, it can result in a higher misclassification rate. Lastly, sub-concepts within the minority class can pose a challenge, as different sub-concepts may require different models to be accurately classified.

Based on the results of our experiment, it appears that the issue stems from an imbalance between the surface ceramics and the surrounding environment, which includes the soil and crops. To dive deeper into this problem, we require more accurate classification results and effective tools to manage imbalanced data or update learning algorithms. The literature offers various solutions, such as rebalancing the class distribution by resampling the data space at the data level or modifying existing classifier learning algorithms to improve comprehension of the small class of ceramics at the algorithmic level. Binary classification problems can be challenging for boosting algorithms when dealing with imbalanced data. However, boosting algorithms are frequently utilized to enhance the prediction capabilities of weak learners and transform them into strong learners. Among the three primary boosting algorithms, AdaBoost, or Adaptive Boost, is commonly employed as an Ensemble Method in Machine Learning. The fundamental idea behind AdaBoost is to build a model and assign identical weights to all data points. It subsequently assigns higher weights to incorrectly classified points, and the following model emphasises those points with higher weights. This training process continues until a lower error rate is achieved. The basic steps of the research methodology are illustrated in diagram 2 below.

Diagram 2: Further analysis methodology and tools to treat imbalanced data.

4. PRELIMINARY RESULTS

The classifiers used for this study were trained using image samples for three classes: 'ceramics' (class 1), 'soil' (class 2), and 'crops' (class 3). The overall accuracy was estimated using randomly distributed testing pixels to evaluate their performance. Accuracy was calculated as the proportion of correctly predicted samples in the test set divided by the total predictions made on the test set.

Accuracy = Correct Predictions / Total Predictions

The accuracy for class 2 and class 3 (soil and crop) was estimated to be approximately 80%, while for class 1 (ceramics), a relatively low accuracy was reported for all four classifiers. The question was raised about how many testing pixels should be selected to ensure that the assessed accuracy was a reliable estimate of the actual accuracy. Would a larger sample of testing pixels give a more realistic estimate? What should the appropriate number of samples be?

According to [7], the number of samples required for an accuracy of 90% is 225, while 119 testing pixels are required for a 95% accuracy. These numbers assume that the classes follow a normal distribution, where a set of measurements, for instance, the mean, is distributed around the centre of these measurements.

Using 225 testing samples, the accuracy of all classifiers was estimated again. ArcGIS Pro randomly created 225 sampled points for post-classification accuracy assessment using the Image Analyst Toolbox. The sampling scheme was set to randomly distributed points, in which each class had the same number of points. A "Ground Truth" field and a "Classified" field were created in the final attribute table. Finally, we manually updated the Ground Truth field by changing or identifying the set of points and compared these fields using the Compute Confusion Matrix tool.

The ceramics class results showed a wide range of accuracy, with RGB images ranging from 12% to 24% and multispectral images ranging from 23% to 61%, as illustrated in Table 1 below. However, this presents a problem with the misclassification of minority classes. Classifiers tend to accurately predict the majority class while being ineffective in predicting the minority class. Our research proposes a methodology to detect surface ceramics using low-altitude multispectral and RGB cameras based on weak learners to address this issue.

Table 1: Ceramics Accuracy after supervised classification.

	KNN	MAX_Likelihood	SVM	RF
RGB	13%	12%	24%	15%
Multispectral	23%	52%	61%	31%

5. ACCURACY IMPROVEMENTS

Research shows that detecting surface ceramics using low-altitude sensors can yield significant results. However, there are limitations in accurately detecting the minority class of ceramics, which can impact the overall detection accuracy. To address this issue, we approach ceramic surface detection as an "imbalanced data distribution" problem. In previous studies, a problem with misclassifying minority classes, such as archaeological ceramics, was identified. Despite achieving high accuracy, the actual detection rate for the ceramic class remained low. This is because classifiers predict classes with extensive data more accurately than those with limited data.

5.1. Boosting algorithms

Boosting is a powerful machine-learning technique that harnesses the collective power of many rough rules of thumb to generate a single, highly accurate prediction rule. This is achieved by repeatedly using a weak learning algorithm on varying subsets of training examples until a new weak prediction rule is generated. After many iterations, the boosting algorithm combines these weak rules into a robust rule. Boosting is a technique that can be applied to any base learning algorithm by assigning greater weight to challenging examples and combining weak rules through majority voting.

In 1995, researchers [8] and [9] created the AdaBoost algorithm to improve the classification performance of other learning algorithms. AdaBoost is the first adaptive boosting algorithm that adjusts its parameters based on data performance. This includes re-weighting data and computing weights for final aggregation iteratively. The boosting algorithm comprises several steps, including:

Step 1: Initialise weights - At the beginning of the process, each training example is given equal weight.

Step 2: Train a weak learner - The weighted training data is used to train a weak learner. A weak learner is a simple model

that performs slightly better than random guessing. A decision tree with a few levels can be used as a weak learner.
Step 3: Error calculation - The error of the weak learner on the training data is computed. The weighted sum of incorrectly classified cases constitutes the error.
Step 4: Update weights - Weights are updated based on the error rate of the training examples. Misclassified examples are given higher weights, while correctly classified examples are given lower weights.
Step 5: Repeat - Steps 2 to 4 are repeated multiple times. A new weak learner is trained on each cycle's updated weights of the training examples.
Step 6: Combine weak learners - The final model comprises all the weak learners trained in the previous steps. The accuracy of each weak learner is weighted, and the final prediction is based on the weighted sum of the weak learners.
Step 7: Forecast - The completed model is used to predict the class labels of new instances.

Our decision-making framework now includes AdaBoost, resulting in significantly improved prediction accuracy compared to using only a decision tree. Ongoing interdisciplinary efforts involve testing and parameterizing algorithms, with the expectation of further improvements in accuracy.

6. CONCLUSION

Our research focused on determining the feasibility of using artificial intelligence techniques to automatically detect archaeological ceramics from high-resolution images captured by unmanned aerial vehicles (UAVs). We also aimed to establish a methodology that can deliver results in terms of time and accuracy comparable to, if not better than, those obtained through traditional archaeological field surveys. To achieve this, we employed supervised machine learning algorithms that utilized RGB and multispectral images acquired from a UAV.

Based on the methodology presented by [5], the findings of this study demonstrate that low-altitude remote sensing sensors can be highly effective in archaeological research. The classifiers employed in the study could predict majority classes (soil and crops) with high accuracy but could not accurately predict minority classes (surface ceramics). A new methodology has been proposed to improve the accuracy of detecting surface ceramics using drone images. This approach involves a boosting technique for weak learners and utilizes RGB and multispectral images. The resulting method provides more reliable and precise results, significantly improving the previous technique.

The authors plan to expand their research on ceramics to include different types from various periods and spectral behaviors in the same area. To achieve this, they will conduct lab-based spectral measurements to ensure statistically significant spectral separability among the ceramics during the same flight. The team scheduled drone surveys to improve data for algorithm training and outcome assessment. Aiming to reduce noise, enhance separability, and evaluate imbalanced ceramics data using measures like F-measure, G-mean, and ROC analysis.

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12. ACKNOWLEDGEMENT

This project has received funding from the European Union's Horizon Europe Framework Programme (HORIZON-WIDERA-2021-ACCESS-03, Twinning Call) under the grant agreement No 101079377 and the UKRI under project number 10050486. Views and opinions expressed are, however, those of the author(s) only and do not necessarily reflect those of the European Union or the UKRI. Neither the European Union nor the UKRI can be held responsible for them.

ARCHAEOLOGICAL SURFACE CERAMICS DETECTION USING LOW ALTITUDE IMAGES BASED ON WEAK LEARNERS

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IEEE IGARSS 2024 July 7-12 ATHENS GREECE

Introduction

In recent years, the field of remote sensing science has seen significant advancements, particularly in its application to support archaeological research [1,2]. These technological innovations, including the improvements of space-based sensors in terms of their spatial and spectral resolution, and the adoption of open access and free distribution of satellite datasets (such as Landsat and Sentinel products), have opened up exciting new possibilities for space-based remote sensing applications [3]. The democratization of low-altitude systems, with drones now available at relatively low costs, has further expanded the scope of archaeological research, particularly for documentation purposes [4]. At the same time, there has been a notable shift in archaeological computational approaches from desktop-based applications to cloud-based approaches, often integrated with advanced AI algorithms [5]. These changes, occurring in a relatively short period, suggest that we are at the dawn of a new era in what can be termed "remote sensing archaeology". In 2019, Orengo and Garcia-Molsosa [5] demonstrated the great potential of the Google Earth Engine big data cloud platform in detecting archaeological potsherds. Their pioneering work, the first of its kind, aimed to advance low altitude technologies with remote sensing methodologies for archaeological surface detection. The purpose of our research is to delve into the potential of Artificial Intelligence (AI) algorithms in classifying and detecting archaeological surface ceramics using low-altitude sensor cameras. We aim to demonstrate how an interdisciplinary approach between Remote Sensing and Artificial Intelligence can effectively overcome the 'accuracy paradox' phenomenon of working with imbalanced remote sensing data implementing weak learners.

Methodology

This research uses Artificial Intelligence (AI) algorithms to classify archaeological ceramic surfaces. Images are captured using low-altitude sensor cameras mounted on two drones. Computational processing is done using ArcGIS Pro software's Image Analyst tools. The process involves creating a training model with three classes(Ceramics, Soil and Crops) and applying four supervised classifiers to the data (K-Nearest Neighbour (KNN), Random Forest (RF), Support Vector Machine (SVM), and the Maximum Likelihood algorithm). The accuracy is assessed by comparing the classification to detailed images and evaluating the results using a confusion matrix per classifier The methodology is illustrated in the figure 1 below.

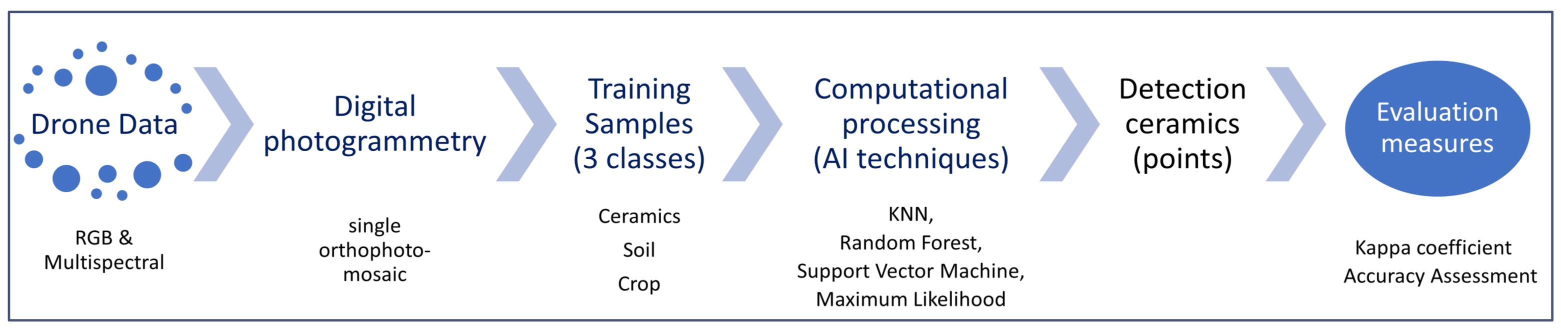

Figure 1. Research methodology.

The field of standard classifier learning algorithms encounters challenges when faced with imbalanced data sets, where the proportion of classes is skewed. This can affect the accuracy of minority class modeling. Issues such as small sample sizes, separability, and sub-concepts influence the effectiveness of the models. To address this, solutions such as resampling data or modifying learning algorithms can be employed. Boosting algorithms like AdaBoost can help enhance predictions in machine learning by assigning higher weights to incorrectly classified points during the training process. (See next diagram)

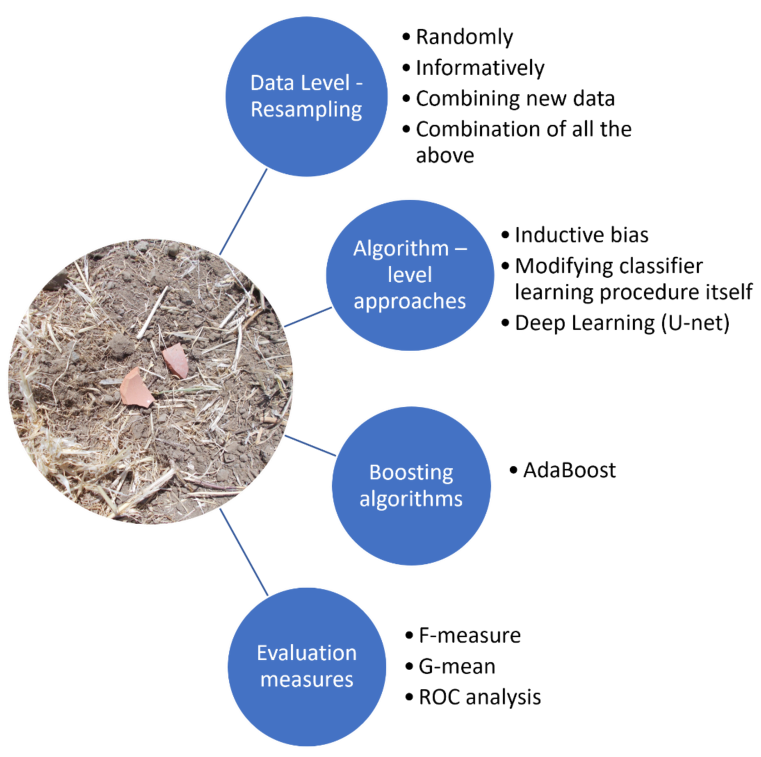

Diagram: Further analysis methodology and tools to treat imbalanced data.

Results

The study utilized classifiers trained on image samples for three categories: 'ceramics', 'soil', and 'crops'. Overall accuracy was determined by using randomly distributed testing pixels. Accuracy was calculated as the proportion of correctly predicted samples in the test set divided by the total predictions made.

Accuracy = Correct Predictions / Total Predictions

In our study, we found that the accuracy for soil and crop classification was around 80%, while it was lower for ceramics. Concerns were raised about the number of testing pixels needed to reliably estimate accuracy. Referring to [7], we determined that 225 samples were required for 90% accuracy, and 119 testing pixels were needed for 95% accuracy. These figures assume that the classes follow a normal distribution. When we used 225 testing samples, we re-evaluated the accuracy of all classifiers. Results illustrated in Table 1 below.

	KNN	MAX Likelihood	SVM	RF
RGB	13%	12%	24%	15%
Multispectral	23%	52%	61%	31%

Table 1. Ceramics Accuracy after supervised classification

Acknowledgments

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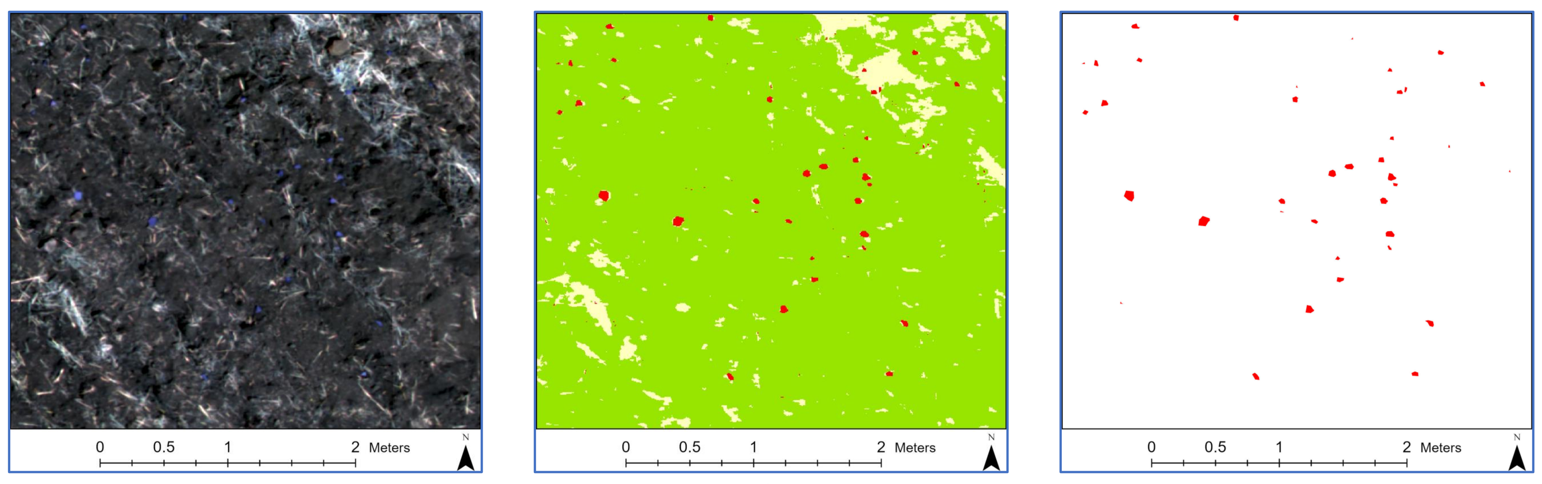
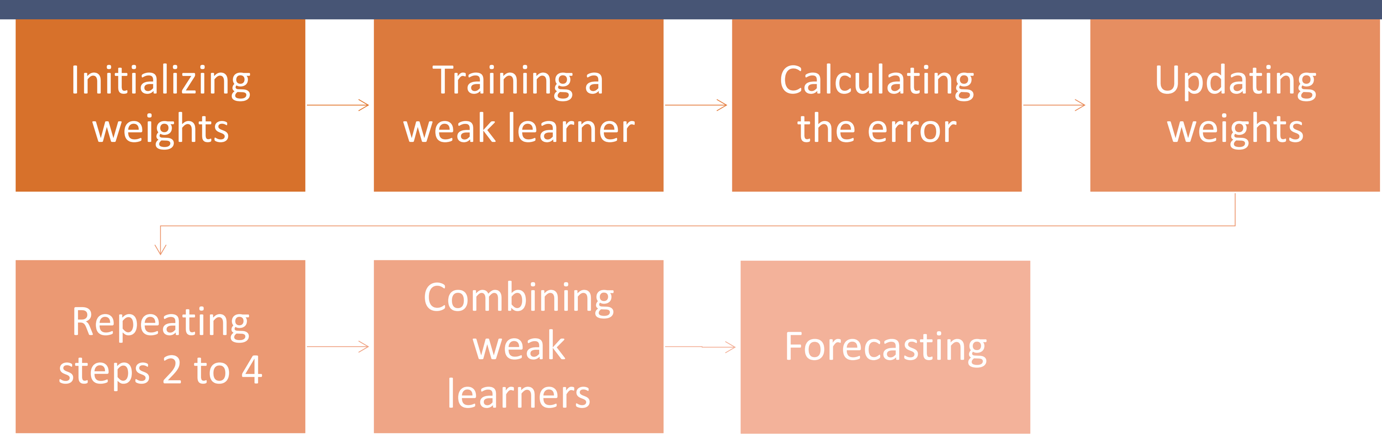


(a) (b) (c)

Example of a zoom area: (a) Input multispectral image, (b) Classification using Support Vector Machine indicating with red colour the ceramics, (c) Detected ceramics.

Accuracy Improvements

To address this issue of misclassifying minority classes our research suggests a methodology for detecting surface ceramics using low-altitude multispectral and RGB cameras based on weak learners. In 1995, researchers [8] and [9] developed the AdaBoost algorithm to improve the classification performance of other learning algorithms. It adjusts its parameters based on data performance by re-weighting data and computing weights for final aggregation iteratively. Using AdaBoost in our decision-making framework has significantly improved prediction accuracy compared to using only a decision tree. The boosting algorithm involves several steps:



Conclusion

Our research focused on using AI to detect archaeological ceramics from high-resolution images captured by UAVs. We employed supervised machine learning algorithms using RGB and multispectral images. The classifiers employed in the study could predict majority classes (soil and crops) with high accuracy but could not accurately predict minority classes (surface ceramics). A new methodology has been proposed to improve the accuracy of detecting surface ceramics using drone images. This approach involves a boosting technique for weak learners and utilizes RGB and multispectral images. The resulting method provides more reliable and precise results, significantly improving the previous technique.. We plan to expand our research to include different types of ceramics and spectral behaviors in the same area and conduct drone surveys for algorithm training and outcome assessment.

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Promoting Research and Innovation for Cultural Heritage in Cyprus through the CONNECTING Infrastructure Project

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Abstract. The "Research and Innovation Knowledge Centre for Engineering in Heritage" project, in short CONNECTING, aims to establish a knowledge centre equipped with advanced sensors and platforms such as Vertical Take-off and Landing (VTOL) drones, cameras, LiDAR systems, laser scanners, and various other sensors to support research on cultural heritage sites and monuments, both on land and underwater. The knowledge centre will serve as a hub for supporting local research in Cyprus dealing with cultural heritage. The project brings together a multidisciplinary team involving experts from the domains of geomatics, civil engineers, Information, Communication and Technology (ICT)experts, archaeologists, and heritage managers. This collaborative effort will enable the selection of appropriate methods, techniques, and tools to support heritage sites, management, and preservation. The project will also develop a cloud Data Centre to store and share evidence, results, services, and products. This paper serves as an introduction to the scope and objectives of the project, while it also outlines the infrastructure that is expected to be acquired and hosted at the Cyprus University of Technology premises.

Keywords: Cultural Heritage, Documentation, Remote Sensors, UAV, Earth Observation, Underwater Object Detection.

1 Introduction

The thematic priority of the CONNECTING project is closely connected with the Smart Specialisation Strategy of Cyprus (S3Cy). The S3Cy aims to facilitate the future sustainable development of the country by leveraging its unique characteristics and research ecosystem (Fig. 1). The final report of S3Cy emphasizes the significance of cultural heritage as a central pillar for the country's future development. It highlights the interaction of cultural heritage with other disciplines, such as tourism - a significant economic revenue stream for Cyprus - and ICT.

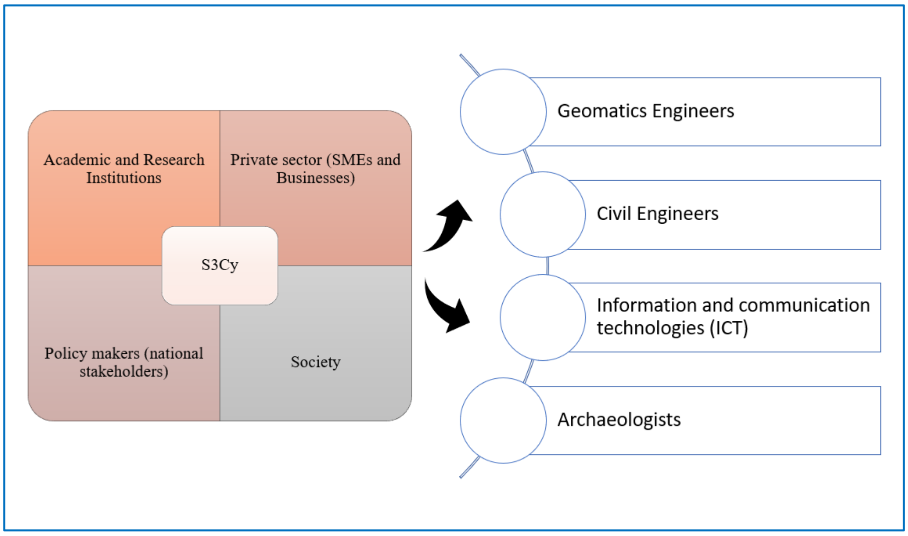

Fig. 1. The CONNECTING project's links with the Smart Specialisation Strategy of Cyprus

The CONNECTING project aligns with the European Commission's vision to establish a collaborative European cloud for cultural heritage by 2025. This initiative aims to facilitate extensive collaboration between cultural heritage professionals across the EU using advanced digital tools to preserve European cultural treasures through a digital infrastructure. The project aims to foster cooperation between the partners and stakeholders of the local research and innovation (R&I) ecosystem, leveraging targeted coordination and support actions (CSA). The project involves academic laboratories at the Cyprus University of Technology (CUT), the Archaeological Research Unit of the University of Cyprus (UCY), and the private sector (Infralabs). The project's development of a multidisciplinary knowledge center, unique in its thematic domain at a national level, is anticipated to support strategic goals defined by the Department of Antiquities of Cyprus (DoA), the single responsible authority in Cyprus for all monuments and sites. Additionally, the knowledge, expertise, and infrastructure gained, could be utilized to support needs beyond the cultural heritage sector, such as mapping and cartographic purposes. The project's actions are backed by wider society involvement, including the UNESCO Chair of Digital Heritage, bridging the collaboration gap between academia, stakeholders, society, and the private/business sector.

The hub aims to enhance research excellence and support future research and innovation collaborations within the region and the broader European context. The knowledge center is expected to accommodate a critical mass of high-level researchers, while attracting well-trained young researchers who can effectively utilize the research infrastructures and propel the consortium to the forefront of relevant research. The project will take all necessary actions to ensure effective infrastructure sharing with the wider society. It will also include educational activities for both undergraduate and postgraduate students and PhD candidates, providing targeted skills during the project's demonstration actions.

2 The aim

The general objectives of the project are presented below.

- The CONNECTING knowledge centre aims to serve as a research hub for the consortium partners and supporters. These entities will collaborate to achieve the two R&I demonstration activities outlined in the project. Actions will include best practices for detecting, monitoring, documenting, and analyzing heritage sites on land and underwater.
- The consortium also aims to comply with the "Strategic Infrastructures" research call regulations and the ERA priority for infrastructure openness. A secure and privacy-preserving cloud data center will host, process, and share project information with specific restrictions for sensitive data.
- The project is expected to enhance research excellence and innovation capacity in geomatics, ICT, archaeology, and civil engineering in heritage. The equipment claimed by CONNECTING will be demonstrated and disseminated through targeted actions. Stakeholders from the private sector and wider society will be engaged, and the infrastructure will be accessible to the local R&I ecosystem, supporting national priorities for open science practices.
- An additional objective of CONECTING is to create a critical mass of researchers in cutting-edge sectors to generate job opportunities for young scientists. Aim for a team of five well-trained researchers at the R&I knowledge center by project end, with potential for further research opportunities from competitive funds.
- CONNECTING also seeks to attract highly skilled researchers to Cyprus by announcing new job openings in geomatics, archaeology, ICT, and civil engineering for heritage-related projects. The proposed infrastructure and interconnected Data Centre, along with targeted skill development activities, will likely capture high-level researchers' attention.
- CONNECTING will ultimately promote effective national research collaboration supported by the partners of the project. This aims to foster synergies in the local R&I ecosystem through two targeted demonstrations on land and underwater, executed collaboratively by the project's end.

3 Proposed Research Infrastructure Gains

The CONNECTING consortium will be outfitted with cutting-edge ground-based terrestrial laser scanners and sensors to monitor the stability of monuments and sites, as well as low-altitude active and passive sensors such as LiDAR, RGB, and multi- and hyperspectral drone sensors. These tools are designed for quick and precise assessments, generating high-resolution thematic maps, and creating 3D representations of landscapes and urban areas. They bridge the observation gap between satellite and ground-based data and can also be utilized for underwater applications. An overview of the proposed infrastructure to be acquired is depicted in Fig. 2.

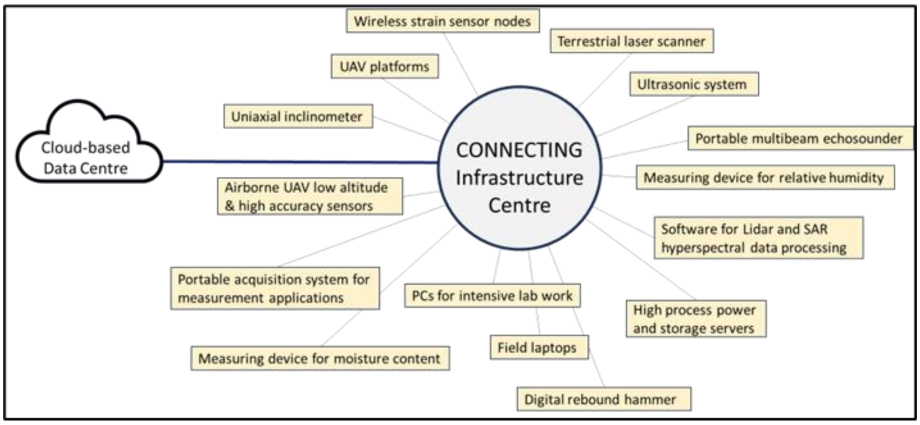

Fig. 2. Proposed research infrastructure of the CONNECTING project

3.1 UAV Platforms (VTOL Quadcopter)

This platform offers extended endurance, thanks to long flight times and weatherproof capabilities. In addition, it integrates advanced AI capabilities with directional sensing and positioning sensors. The proposed drone is engineered to meet all new EASA standards by combining intelligence with high performance and exceptional reliability. The system comes equipped with all necessary components for immediate deployment, including intelligent batteries, a battery station, a specially designed controller, and more. Furthermore, it features an advanced RTK high-precision GNSS receiver that supports all major global satellite navigation systems, delivering real-time differential corrections to generate centimeter-level positioning data for improved accuracy in 2D and 3D mapping.

3.2 Airborne UAV Low Altitude & High Accuracy Sensors (Lidar, mapping RGB, Hyperspectral)

The sensor package comprises a high-performance surveying payload tailored to map 2D and 3D infrastructures. It is specifically designed to minimize distortions in open spaces. The package also includes an aerial LiDAR payload capable of generating highly detailed 3D point clouds of features that may not be visible in 2D mapping. Moreover, it is equipped with a drone-specific hyperspectral camera that can livestream real-time data to the remote-control during flight. This camera can capture RGB and HSI images simultaneously and is equipped with a built-in GPU for additional pre-processing. Lastly, the package automatically processes overview images to evaluate correct exposure settings and depict acquired spatial and spectral information.

3.3 High Process Power and Storage Servers

We require a high-performance computer capable of processing a wide range of data gathered from both airborne and ground sensors. It should handle dense 2D and 3D geoinformation, including dense 3D point clouds and hypercubes. Employing parallel data processing will enhance computing performance and enable complex calculations, ensuring efficient, reliable, and prompt operation of advanced applications in line with user needs and expectations. A Storage Server will also be necessary to store the project's data and applications. These servers will serve as repositories for data and applications, offering rapid and dependable access to large volumes of data over a shared network or the Internet. The server will also house the cloud Data Centre.
Researchers will have access to PCs for processing data and running intensive spatial calculations for 2D or 3D data analysis. Additionally, field laptops will be utilized as ground control stations during drone data acquisition, using specially designed software. Ground Control Stations (GCS) enable UAV operators to communicate with and control the drone and its payloads. This can be achieved by setting parameters for autonomous operation or by directly controlling the UAV.

3.4 Software for Process Lidar and SAR and Hyperspectral Data

The processing of 3D point clouds from aerial or ground lidar systems, as well as the integration of design and as-built models, requires specific software. This software creates and visualizes point clouds in a meaningful way, and can produce high-quality videos, screenshots, and orthophotos. It also enables annotation, measurement, and virtual environment tours, along with the extraction of floor plans and elevations from point clouds. Additionally, efficient software for hyperspectral and SAR imaging is essential for accurately processing hyperspectral images under variable lighting conditions.

3.5 Terrestrial Laser Scanner

The terrestrial laser scanner (TLS) as a ground-based alternative to airborne LIDAR for indoor terrain and landscape mapping. Terrestrial laser scanners, a relatively recent innovation, provide high-resolution mapping for deformation measurements, quality control, topographical surveying, and cultural heritage monitoring.

4 Discussion

CONNECTING project pathways to impact involves supporting emerging multidisciplinary needs for monitoring, documenting, analyzing, and preserving cultural heritage sites on land and underwater. The project results include know-how in data collection and integration in cultural heritage, implementing a cloud Data Centre, developing geospatial fusion techniques, and creating databases and datasets of cultural heritage sites. Additionally, the project aims to implement security measures, establish guidelines for standards, and train researchers. A Communication, Dissemination, and Exploitation plan will support the project outcomes. The project will focus on reaching academia, the research community, professionals, private industry, stakeholders, public authorities, and the public interested in innovative technologies, research, cultural heritage, and schools. The outcomes will showcase the potential of the infrastructure, making it open to external users and potential collaborators. New technologies for heritage documentation have the potential to impact a range of economic, social, and technological developments.

Indeed, the Knowledge Centre for Cultural Heritage will be closely linked to the Smart Specialisation Strategy of Cyprus (S3CY) for the country's sustainable development. Using new technologies for heritage documentation will increase public awareness and appreciation of cultural heritage and facilitate knowledge sharing and cultural exchange. The impact of technological development involves connecting cloud data centers and demonstrating new technology for cultural heritage documentation. This can drive innovation in fields like computer vision, machine learning, and robotics, leading to new tools and software creation. These technologies also can support new applications in urban planning, architecture, and geospatial analysis. The project's use of new technologies for cultural heritage documentation can drive economic growth in tourism, conservation, and cultural heritage management. Accurate documentation of heritage sites can attract more visitors, increase tourism revenue, and stimulate investment in restoration and conservation efforts. The project also aims to promote the development of new technologies for heritage documentation, creating opportunities for businesses to develop and market new products and services like virtual tours and online education programs.

The CONNECTING project can have a positive environmental impact by reducing the need for on-site visits and traditional surveying methods, which generate carbon emissions. The CONNECTING knowledge center will minimize travel and support remote data collection, while innovative technologies for heritage documentation can help reduce the carbon footprint of conservation and research efforts.

Acknowledgments. This project has received funding from the European Regional Development Fund and the Republic of Cyprus through the Research and Innovation Foundation of Cyprus under contract SMALL SCALE INFRASTRUCTURES/1222/0062.

Disclosure of Interests. The authors have no competing interests to declare that are relevant to the content of this article.

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Connecting

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2nd - 4th December 2024

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Introduction

The project for the "Research and Innovation Knowledge Centre for Engineering in Heritage," also known as **CONNECTING**, is a project that focuses on improving the way we preserve heritage sites and monuments and Aims to create a knowledge center for cultural heritage research. This center will be equipped with advanced sensors and platforms, such as vertical takeoff and landing drones (VTOL), RGB, multi- and hyperspectral cameras, LiDAR systems, terrestrial laser scanners, soil moisture sensors, ultrasonic sensors, inclinometers, wireless strain sensors, and multibeam echosounders. These tools will enable researchers to identify, monitor, document, and analyze cultural heritage sites and monuments on land and underwater, promoting research excellence.

The aim

The thematic priority of the **CONNECTING** project is closely connected with the Smart Specialisation Strategy of Cyprus (S3Cy). The S3Cy aims to facilitate the future sustainable development of the country by leveraging its unique characteristics and research ecosystem Figure 1. The final report of S3Cy emphasizes the significance of cultural heritage as a central pillar for the country's future development. It highlights the interaction of cultural heritage with other disciplines, such as tourism - a significant economic revenue stream for Cyprus - and Information and Communications Technology (ICT).

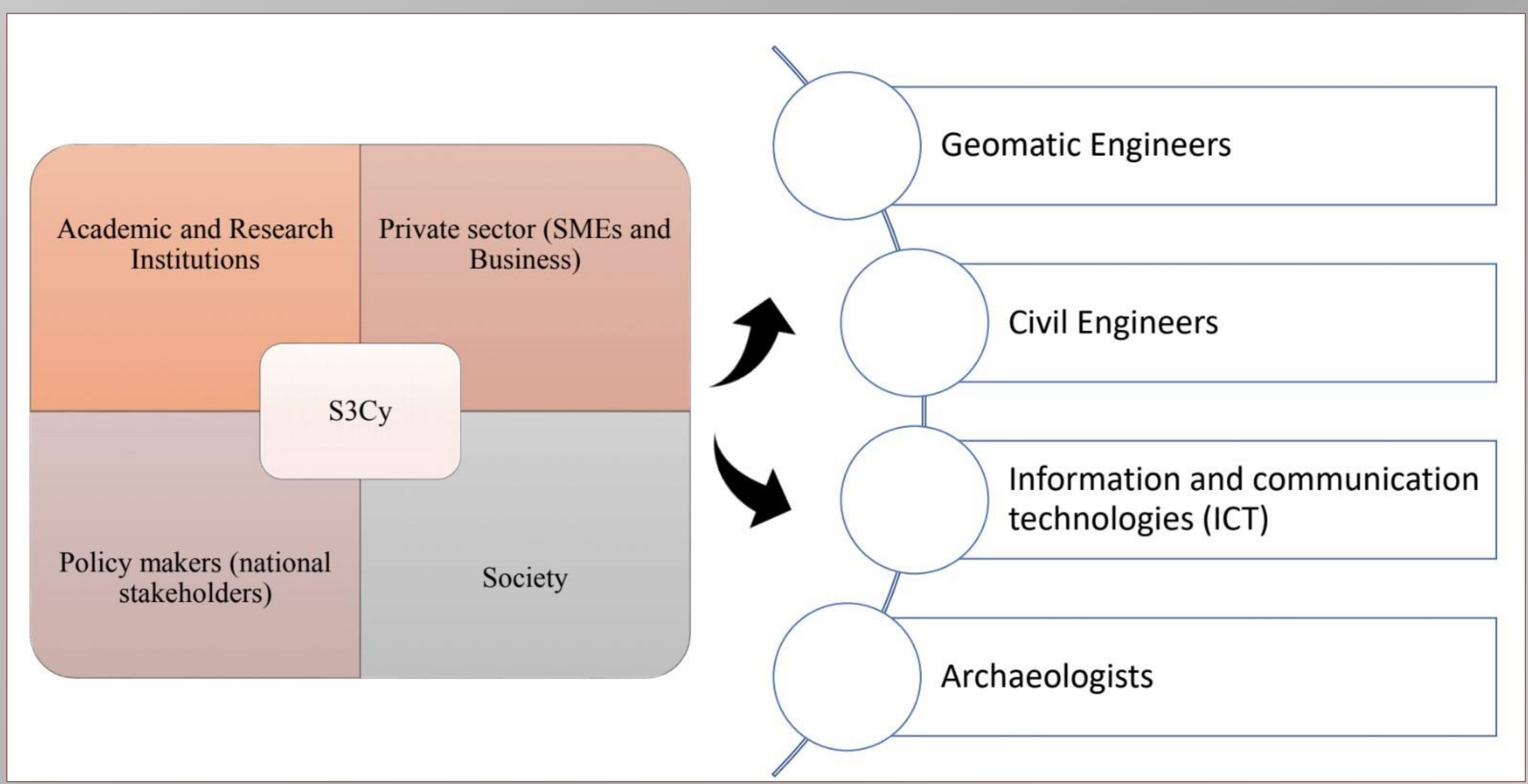
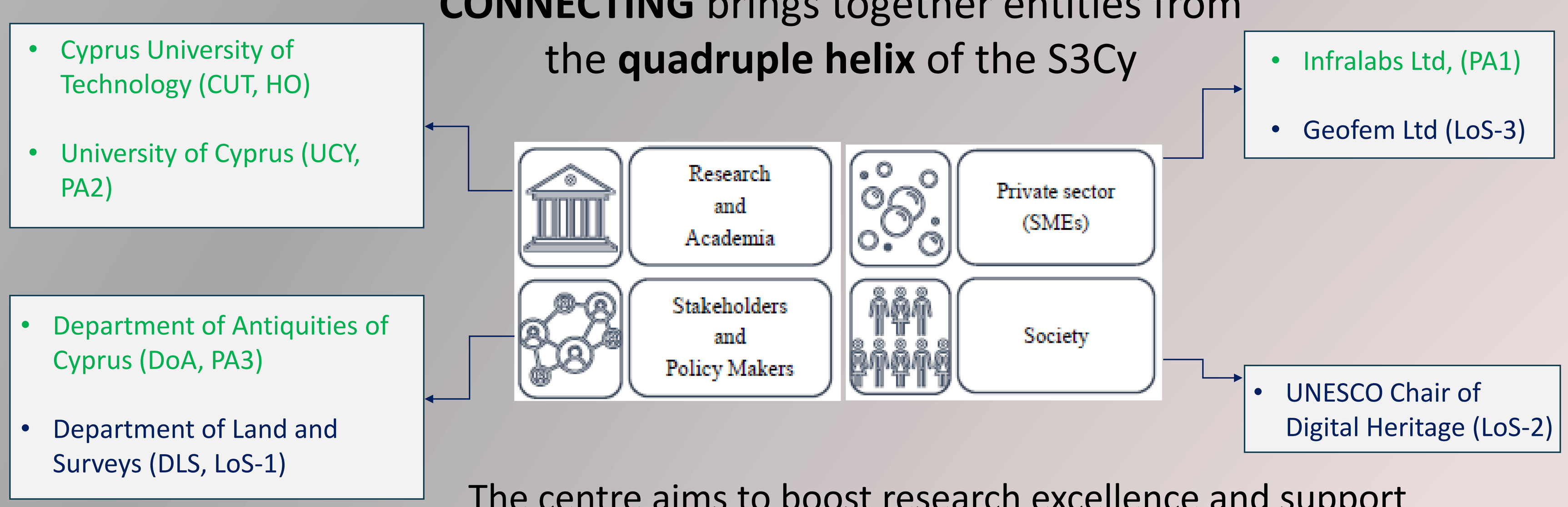


Figure 1. The CONNECTING project linked with the Smart Specialisation Strategy of Cyprus

CONNECTING brings together entities from the **quadruple helix** of the S3Cy

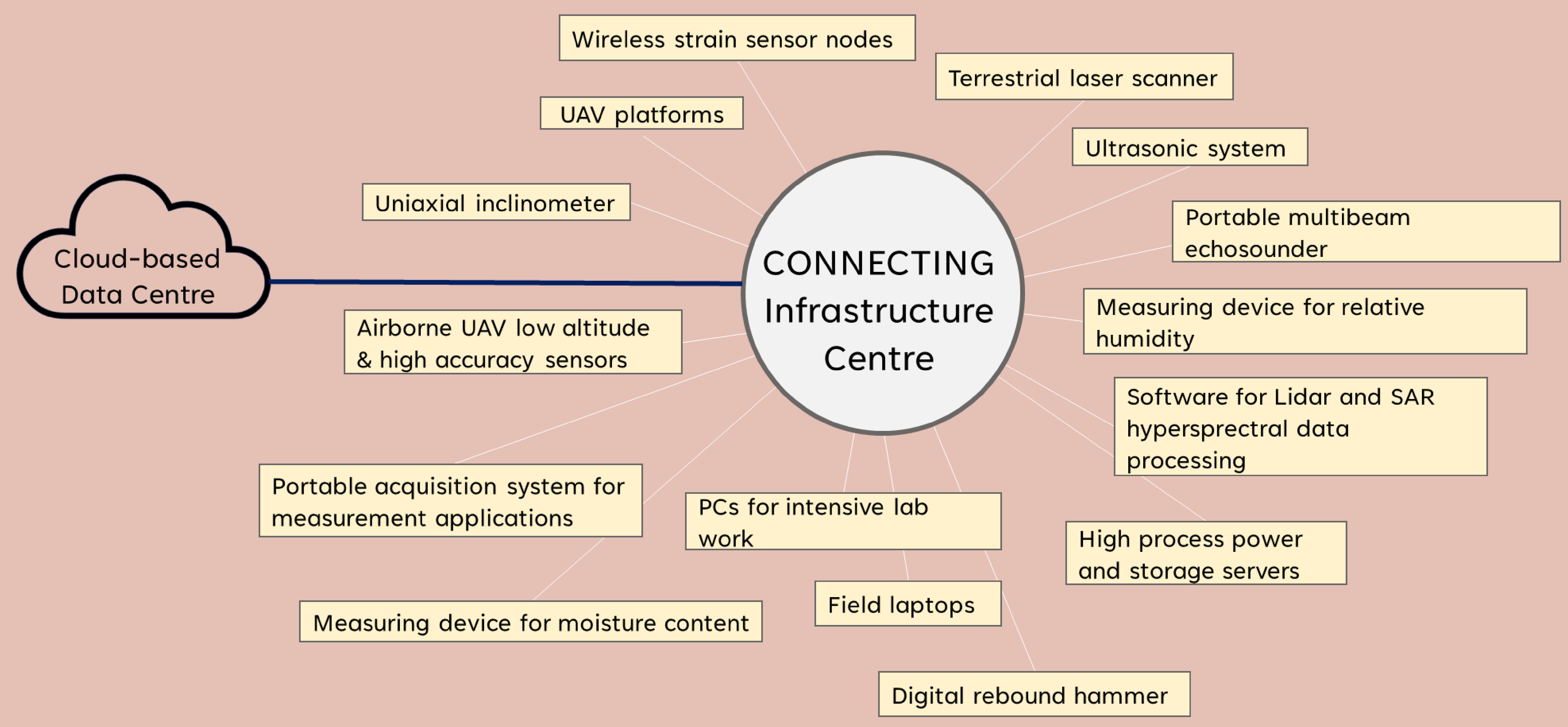


The centre aims to boost research excellence and support future R&I synergies via creating strong links with relevant European advance institutions such as the **University College of London (UCL, LoS-4)**, the **Politecnico di Milano (POLIMI, LoS-5)** and the **University of Aveiro (UAVEIRO, LoS-6)**

- The CONNECTING knowledge centre will serve as a research hub for the consortium partners and supporters. Actions include best practices for detecting, monitoring, documenting, and analyzing heritage sites on land and underwater.
- A secure and privacy-preserving cloud data center will host, process, and share project information with specific restrictions for sensitive data.
- Enhance research excellence and innovation capacity in geomatics, ICT, archaeology, and civil engineering in heritage. The equipment claimed by CONNECTING will be demonstrated and disseminated through targeted actions.
- Create a critical mass of researchers in cutting-edge sectors to generate job opportunities for young scientists.
- Attract highly skilled researchers to Cyprus by announcing new job openings in geomatics, archaeology, ICT, and civil engineering for heritage-related projects.
- Promote effective national research collaboration supported by the partners of the project.

Proposed Infrastructure

The **CONNECTING** project aligns with the European Commission's vision to establish a collaborative European cloud for cultural heritage by 2025.



Benefits

Impact on Multidisciplinary Needs:

- Support monitoring, documentation, analysis, and preservation of cultural heritage sites on land and underwater.
- Implement security measures, establishes standards, and provides training for researchers.

Communication, Dissemination, and Outreach:

- Promote innovative technologies and research for cultural heritage.
- Open infrastructure to external users and collaborators

Technological Advancements and Applications:

- Enhance computer vision, machine learning, robotics, and other technology fields.
- Support new applications in urban planning, architecture, and geospatial analysis.
- Develop tools, software, and services like virtual tours and online education.

Economic Impact:

- Innovation and economic growth in tourism, conservation, and cultural heritage management.
- Attract more visitors and stimulates investments in restoration and conservation.

Public Awareness and Cultural Exchange:

- Increase public appreciation of cultural heritage.
- Facilitates knowledge sharing and cultural exchange

Environmental Benefits:

- Reduce on-site visits and traditional surveying, cutting carbon emissions.
- Promote remote data collection and minimize travel through innovative technologies.
- Support sustainable conservation and research efforts.

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Disclosure of Interests. [1]The authors have no competing interests to declare that are relevant to the content of this article.

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SCAN ME

Innovative Geospatial and Engineering Solutions for Cultural Heritage

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Abstract. Cultural heritage is facing increasing vulnerability due to various threats, including natural disasters, human activities, and the escalating impacts of climate change. This study examines how geospatial technologies and engineering solutions can address these issues, emphasizing their potential to improve monitoring, protection, and preservation practices for cultural heritage sites. Advanced geospatial technologies, such as non-contact geomatics sensors and structural analysis techniques, offer further capabilities for heritage monitoring. These tools enable the development of early warning systems to proactively identify and mitigate risks to monuments before significant damage occurs. Such systems support timely interventions, reducing restoration costs and safeguarding the integrity of heritage assets. By integrating advanced technologies with field-specific requirements, this study provides an overview of effective resource allocation. This paper highlights the objectives of two recently supported European and national ongoing projects of the Cyprus University of Technology (CUT), namely the "Geomatics and Civil Engineering Innovative Research on Heritage", in short ENGINEER and the "Research and Innovation Knowledge Centre for Engineering in Heritage", in short CONNECTING. Both projects' tasks aim to fill research multidisciplinary gaps, push, and extend knowledge into new and innovative fields dealing with the monitoring, digitization, visualization, and preservation of heritage monuments and cultural heritage sites, assisting their protection, promotion, and safeguarding with the contribution research activities through coordination and support actions as well as through targeted research activities with the support of European leading institutions.

Keywords: Cultural Heritage, Documentation, Remote Sensors, UAV, Earth Observation, Underwater Object Detection.

1 Intoduction

Cultural heritage is challenged with several threats, either natural or anthropogenic, including the far-reaching impacts of climate change, as highlighted by studies [1,2]. These challenges need to be addressed several times with significant financial constraints, and therefore the exploration of innovative and interdisciplinary solutions need to be further explored. To effectively address these issues, innovative approaches that can enhance our existing methods of heritage conservation are needed. These approaches can lead to a deeper appreciation for, as well as more robust protection and monitoring of, our invaluable heritage sites that reflect our history and identity.

To achieve this goal, we need to develop standardized methodologies that integrate cutting-edge technologies. For instance, non-contact geomatics sensors can provide detailed data regarding the geometry, shape and status of a site, without physically disturbing the sites. In addition, advanced structural analysis techniques can assess the integrity of these structures under stress. Additionally, conservation engineering can offer insights into best practices for maintaining the stability and longevity of h eritage sites.

By utilizing these advanced tools and technologies, we can establish early warning systems that identify at-risk monuments before damage occurs. This proactive approach not only aids in the preservation of these sites but also fosters a greater understanding of their historical significance and the factors that threaten them. Overall, enhancing our capabilities in heritage research and conservation is crucial for ensuring that future generations can appreciate and learn from these cultural treasures.

2 Addressing Research Gaps and End-User Requirements

Understanding the nature of captured data is of paramount importance when it comes to applying it effectively to specific conservation outcomes. This understanding is also critical for meeting the diverse data posed by end-users, which can be accomplished using suitable and cost-effective geomatic methods [3]. Moreover, several challenges remain regarding the potential for multi-use of (heterogenous) data. Such data must be added here to established standards that ensure reliability and compatibility. This adherence not only facilitates its use across different projects but also promotes collaboration on multidisciplinary initiatives, which are increasingly essential in today's complex environmental landscape. Policymakers and users expect high standards that encompass rigorous specifications for data quality, accuracy, and format, adding another layer of complexity to data management in conservation.

In addition to these challenges, there are ongoing concerns surrounding data integration and fusion. The interdisciplinary application of digital techniques requires a thoughtful selection of workflows that accommodate the varied nature of data sources. Data flexibility options must be considered carefully, as they can significantly impact how well different data types and sources can work together. The integration of data from disparate sources presents both opportunities and obstacles, with each source offering unique pathways for integration into a coherent whole.

Furthermore, while adhering to established data types and standards can enhance the potential for maximum data reuse, it is equally important to understand the associated limitations and benefits that come with specific techniques. Each method and sensor carry its own implications for data accuracy, usability, and interoperability. Therefore, a better understanding of these factors is essential for maximizing the effectiveness of conservation efforts and ensuring that the data can be leveraged to its fullest potential across various applications. This comprehensive approach enables more informed decision-making in conservation.

By fostering a synergy between geomatic techniques—such as surveying, mapping, and data analysis—and civil engineering practices, the projects seek to enhance methodologies in the preservation and management of cultural heritage sites [3]. This comprehensive approach promotes knowledge sharing and encourages the development of new technologies and strategies that could significantly benefit heritage engineering. The authors are coordinating two relevant projects (ENGINEER and CONNECTING) that aim to address and bridge existing gaps between geomatic engineering and civil engineering. This collaboration emphasizes integrating these two disciplines through well-structured training programs and targeted research activities.

3 The motivation

The ENGINEER project represents a groundbreaking initiative focusing on innovative research in heritage preservation. Alongside it, the CONNECTING project aims to establish a knowledge centre dedicated to engineering in heritage. The thematic priority of both projects is intricately linked to the Smart Specialisation Strategy of Cyprus (S3Cy). This strategy is designed to foster sustainable development throughout the country, tapping into its unique characteristics and robust research eco-system.

The final report of S3Cy underscores the critical role of cultural heritage as a foundational pillar for the future development of Cyprus. It emphasizes that cultural heritage is not only a source of national pride but also a vital resource that can drive economic growth and innovation. The report details how this cultural heritage interacts with various sectors, particularly tourism, which serves as a significant economic engine for Cyprus [4]. By attracting visitors to its rich historical sites and traditions, tourism contributes substantially to the country's GDP.

Furthermore, the report highlights the potential of integrating information and communication technology (ICT) into cultural heritage initiatives. Utilizing ICT can enhance the preservation, promotion, and accessibility of Cyprus's cultural assets, thereby creating new opportunities for sustainable tourism and economic diversification.

Recent studies conducted across Europe and in various regions around the world have demonstrated that heritage can significantly contribute to the growth of the real economy. This impact is particularly evident through the development of innovative tourism concepts such as cultural tourism, geotourism, and sustainable tourism [1,3]. These forms of tourism not only promote the appreciation and preservation of local culture and natural landscapes but also attract visitors who are eager to engage with and experience unique historical and cultural sites.

Moreover, the construction industry also benefits from heritage initiatives, as the restoration and maintenance of heritage buildings create jobs and stimulate economic activity. The careful preservation of these structures not only protects the architectural and historical significance of communities but also enhances their appeal as tourist destinations. Collectively, these efforts underscore the importance of heritage as an asset that can drive economic growth and sustainability. This collaborative approach between cultural heritage and other disciplines is vital for ensuring the long-term prosperity and resilience of Cyprus in a rapidly changing global landscape.

4 Recent Studies

Developing innovative methodologies for the long-term monitoring of heritage monuments is crucial for ensuring their preservation and resilience. These methodologies should not only account for current conditions but also proactively actively anticipate potential adverse effects such as climate change and geological events like earthquakes. Investing in these preventive measures will be more cost-effective than addressing the consequences that arise once damage has occurred.

The societal impact of losing a heritage monument is profound and irreparable, as these structures embody our history, culture, and identity. Therefore, comprehensive digital documentation of these monuments is essential. This process entails creating detailed records of their condition before potential damage occurs, thus providing a vital baseline for preservation efforts. Digital documentation aids in capturing architectural details, analyzing structural integrity over time identifying early signs of deterioration.

The project's objectives are centred on establishing robust standards and protocols for the ongoing monitoring of built heritage [5]. This includes developing guidelines for data collection, analysis, and reporting and ensuring these standards align with best practices in heritage conservation. By implementing these measures, we can safe-guard our cultural legacy against the growing threats posed by environmental natural disasters, securing the future of these invaluable monuments for generations to come.

4.1 Ground motion data from the EGMS

A recent case study conducted in Cyprus, as part of the multidisciplinary ENGINEER project, showcased the European Ground Motion Service (EGMS) in its ability to deliver consistent and reliable information about ground movement in monuments and heritage sites, achieving millimeter-level accuracy over extensive areas. The EGMS holds significant potential for monitoring cultural heritage sites, acting as an early warning system for local and national authorities tasked with heritage management and protection. Furthermore, the data provided by EGMS is especially beneficial in tracking less accessible regions, which are often challenging to monitor using conventional methods [6].

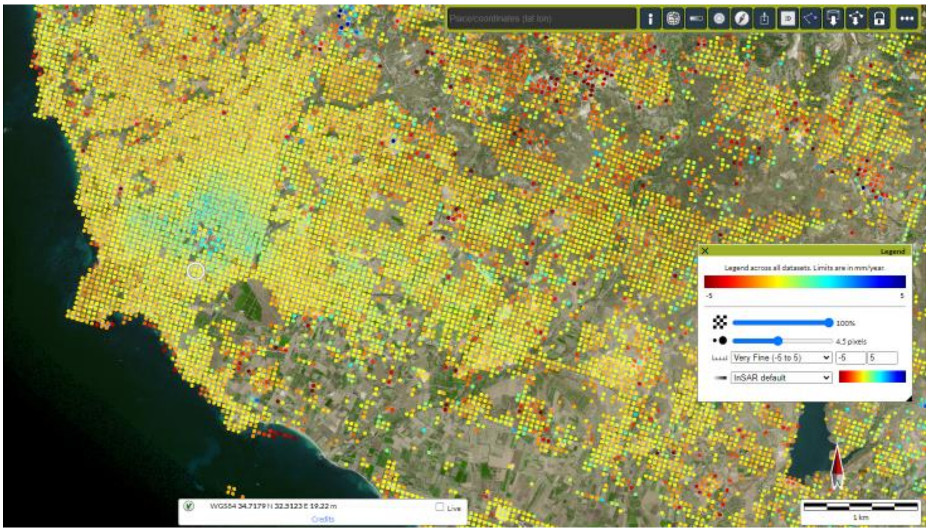

Figure 1. EGMS results over the wider Paphos area [6].

This study was specifically focused on the ground motion data from the EGMS concerning the Paphos district in western Cyprus. Spanning nearly 1,400 square kilometers, the Paphos district accounts for 15.1% of the island's total area (Figure 1). This region houses 147 ancient monuments and archaeological sites that are safeguarded under the Antiq-uities Law of the Republic of Cyprus. Notably, several of these sites, including Ancient Nea Paphos and the Tombs of the Kings, are designated as UNESCO World Heritage Sites. The recorded displacements at the sites of the selected monuments will be applied to the supports of the numerical model, enabling us to calculate the resulting stresses on the monument walls (Figure 2). This methodology takes into account soil-structure interaction and facilitates the mapping of damage patterns on the monuments. Consequently, it will offer valuable insights into the damage caused by ground movement, allowing for a clear distinction between this damage and any damage resulting from prior seismic events.

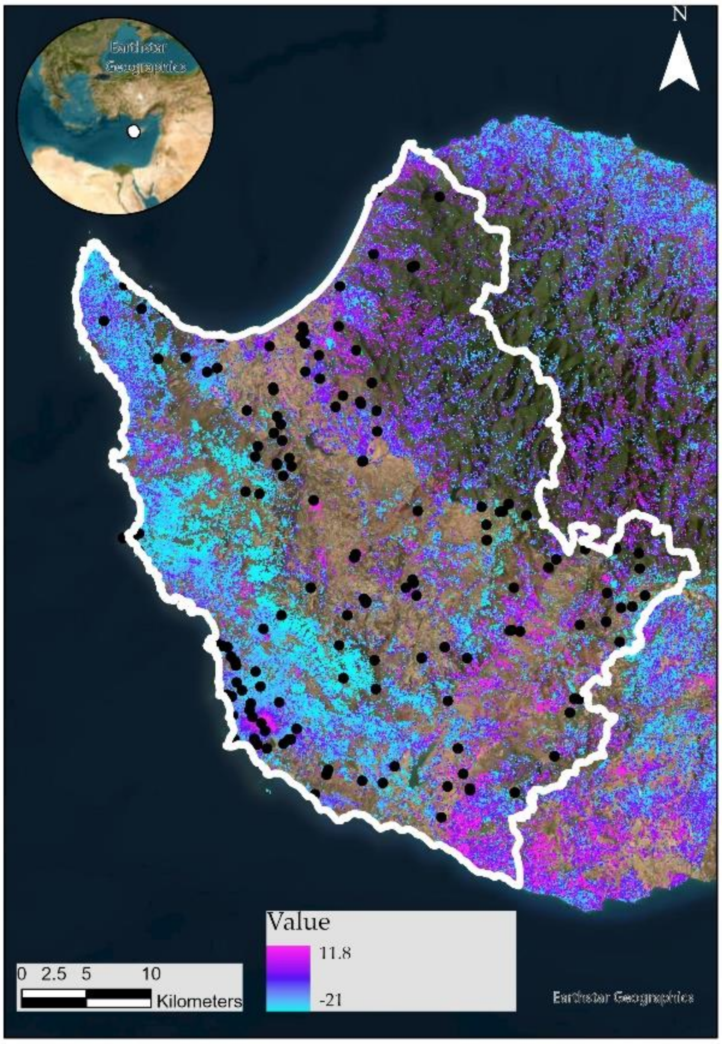

Figure 2. Vertical displacement (expressed in mm) over the Paphos district, using the 2016-2021 EGMS results. Protected archaeological sites are shown with dots [6].

4.2 Monitoring underground heritage sites

The authors have also conducted int the past a detailed case study to investigate the monitoring of underground heritage sites, with a particular emphasis on understanding the relationship between damage conditions and historical seismic activity for tomb T4, located within the Tombs of the Kings Necropolis, which is recognized as a UNESCO World Heritage site (Kyriakides et al., 2017) [7]. This study aimed to assess how past seismic events may have impacted the structural integrity and preservation of the tomb. In addition to the case study, the authors carried out a comprehensive simulation study that utilized data derived from a comparable seismotectonic environment. This simulation was carefully scaled to reflect the anticipated seismic hazards specific to the region of the Tombs of the Kings. The findings aimed to enhance the understanding of risk factors affecting the site and to develop potential strategies for safeguarding these invaluable heritage assets against future seismic threats [3]. Similar work is currently replicated as part of the ENGINEER project for Tomb 7 (see Figure 3) where close range and other photogrammetric data are been used to model the site.

Figure 3. Point cloud using drone data from Tomb 7, "Tombs of the Kings archaeological site" [6].

4.3 The case of the Roman Baths of Amathus in Limassol, Cyprus

In recent years, the integration of geomatic techniques with varying levels of accuracy and resolution has been applied to the geometric documentation of numerous archaeological sites. A case study was conducted on the Roman Baths of Amathus in Limassol, utilizing both aerial photogrammetry and Terrestrial Laser Scanning (TLS) methods to achieve the final results. The archaeological site of Amathus, recognized as a UNESCO World Heritage site, is located 10 km east of Limassol's center. It stands as one of the most important historical sites in Cyprus. This case study examines the Roman Baths and the Doric columns (Figure 4), positioned beyond the Roman market (Agora), which together encompass an area of approximately 625 m² (around 25 m x 25 m) [8].

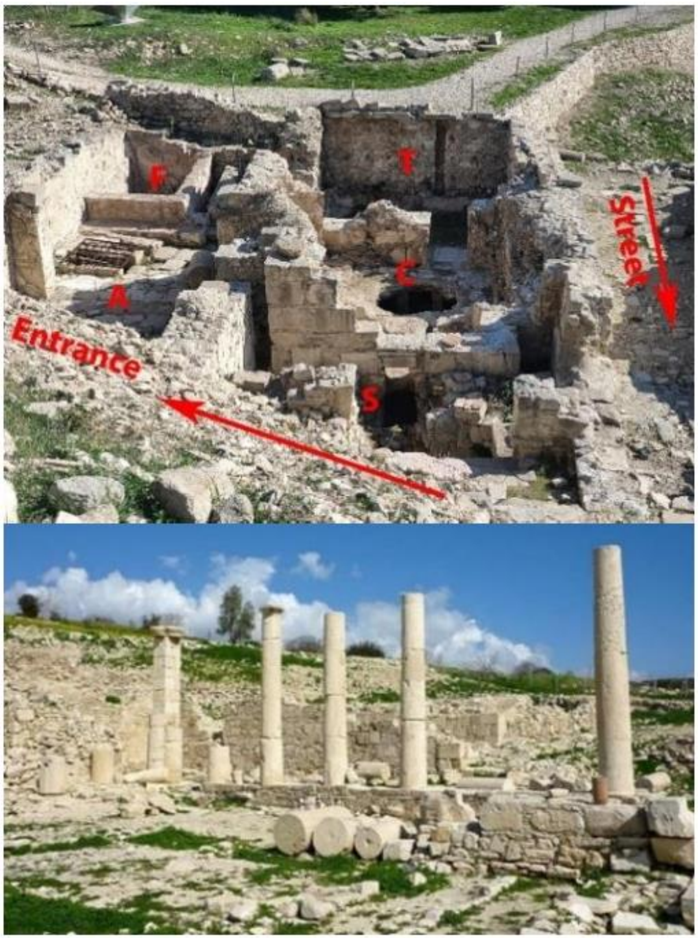

Figure 4. The Roman Baths (above) and the columns (below) [8].

The photogrammetric data were collected using Post-Processed Kinematic (PPK) imagery, while the TLS georeferencing relied on specific targets. The primary aim of this study was to evaluate the reliability of PPK photogrammetric data without the use of Ground Control Points (GCPs) and to assess how effectively these data could be integrated with TLS data. Additionally, the two acquisition techniques were compared, demonstrating that aerial images with a Ground Sampling Distance (GSD) resolution of 0.005 m can be qualitatively fused with TLS scans at a resolution of 0.0061 m per 10 m [8]. This research provides a comprehensive overview of the methodology leading to the development of the final 3D photorealistic product (Figure 5).

Figure 5: Photogrammetric 3D mesh of Roman bath, Amathus [8]

5 Proposed Research Infrastructure Gains

The CONNECTING consortium aims to provide equipment with cutting-edge ground-based terrestrial laser scanners and sensors, known for their versatility in monitoring the stability of monuments and sites [9].

These tools, along with low-altitude active and passive sensors such as LiDAR, RGB, and multi- and hyperspectral drone sensors, are designed for quick and precise assessments. They generate high-resolution thematic maps and create 3D representations of landscapes and urban areas, bridging the observation gap between satellite and ground-based data. Their versatility also extends to underwater applications, offering a wide range of potential uses. The CONNECTING project is designed to support the European Commission's vision of creating a collaborative cloud platform dedicated to cultural heritage by the year 2025. This ambitious initiative seeks to foster meaningful partnerships among cultural heritage professionals throughout the European Union. By leveraging cutting-edge digital tools and technologies, the project aims to enhance the preservation and accessibility of European cultural treasures. The goal is to establish a comprehensive digital infrastructure that allows for effective sharing, collaboration, and innovation within the cultural heritage sector, ensuring that these invaluable resources are safeguarded for future generations [10]. An overview of the proposed infrastructure to be acquired is depicted in Figure 6.

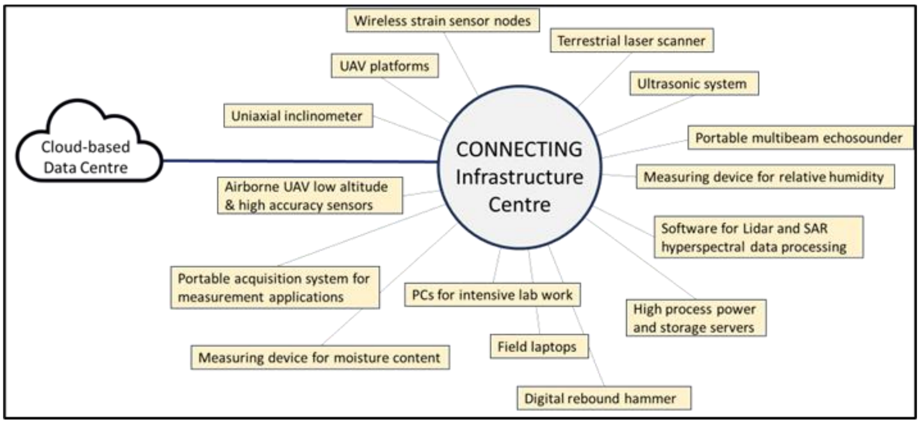

Figure 6: Proposed research infrastructure of the CONNECTING project [8].

The following section, provides a brief overview of the sensors and methodologies currently used for cultural heritage documentation and monitoring, categorized by the platform or environment where they are most used, based on published papers. Indeed, this meta-analysis of the literature review [11] was based on the available literature and published documents accessible from the Scopus engine (accessed on 8 August 2023). A comprehensive series of analyses was conducted, revealing a significant finding regarding the nature of review papers in the field. It was observed that these papers, whether they are published in peer-reviewed scientific journals or presented as part of conference proceedings, concentrate on applications associated with remote sensing and photogrammetry. An overview of the research landscape of heritage based on keywords from several published papers found in Scopus Engine [see more in 9] is depicted in Figure 7.

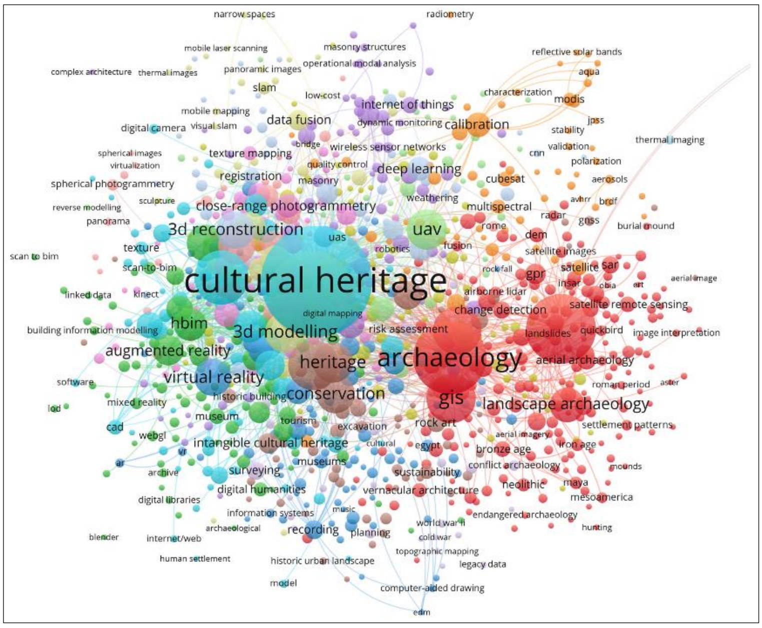

Figure 7: Co-occurrence analysis based on keywords from published papers found in Scopus engine [11].

Emerging fields can be also identified from such literature review analysis. Table 1 generates a summary list of keywords (top 25) associated with citation bursts. The visualization highlights the keywords with the most significant citation bursts and identifies the time periods during which these bursts occurred, marked in red to indicate their start and end. For example, in early 2010, terms like three-dimensional, sensors, calibration, image processing, and satellite were prominent in the literature. Of particular interest are the final rows in Table 1, which reveal emerging trends in research domains, such as the adoption of UAVs, antennas, monitoring, and deep learning. Details regarding the sensors are found in the following subsections.

Table 1. List of keywords (top 25) that are associated with citation bursts (red color indicates the period where the specific keyword is substantial refer to the literature).

Keywords	Year	Strength	Begin	End	2010–2022
three dimensional	2010	83.76	2010	2013	
sensors	2010	32.9	2010	2013	
calibration	2010	25.88	2010	2016	
image processing	2010	23.25	2010	2016	
satellites	2010	20.22	2010	2016	
design	2010	19.42	2010	2012	
research	2010	17.87	2010	2013	

nasa	2010	16.64	2010	2012
photography	2011	26.98	2011	2015
laser scanner	2011	19.09	2011	2013
terrestrial laser scanning	2012	13.76	2012	2017
surface analysis	2010	33.21	2013	2017
system program documentation	2013	19.44	2013	2015
spectroscopy	2013	15.4	2013	2014
information management	2012	16.69	2015	2019
3 d modeling	2012	16.24	2015	2017
close-range photogrammetry	2010	18.41	2016	2017
structure from motion	2013	25.45	2017	2019
uav	2014	19.27	2017	2022
antennas	2017	36.93	2018	2022
heritage	2016	16.03	2018	2022
landscape archaeology	2019	16.18	2019	2020
textures	2012	15.8	2019	2020
monitoring	2010	14.93	2019	2022
deep learning	2020	31.28	2020	2022

5.1 Close-Range Sensors

RGB Sensors

RGB sensors are passive sensors, commonly used for closed-range photogrammetric applications. These sensors operate in the visible part of the spectrum, between 380–750 nm. While CMOS sensors are sensitive to approximately 350–1050 nm, an infrared filter (750–1000 nm) is applied to reproduce natural colors visible to humans. By replacing the infrared filter with a red one, some cameras can be easily customized to near infrared, hence CMOS records infrared wavelengths into the red channel of the RGB image file [11].

This cutting-edge platform is engineered for extended endurance, offering impressive flight times that enable lengthy operational missions in various environments. Its robust design incorporates weatherproof capabilities, making it suitable for a wide range of weather conditions. The variety of RGB cameras available in the cultural heritage sector is unmatched. These cameras are categorized by their sensors and lenses. CMOS sensors are classified by physical size and resolution, while lens characteristics include focal length and ma-terial, with glass preferred over plastic.

Manufacturers prioritize different features based on the camera's intended use and cost. For instance, rigidity is important for 3D reconstruction but may increase weight, complicating drone mounting. Interchangeable lenses offer versatility but add size and weight, and features like LCD screens may be unnecessary for drones. Key features for specific applications include recording in raw format, remote control connections, and synchronization for precise triggering. While primarily used for documentation, these cameras are also employed in 3D reconstruction through techniques like Structure from Motion (SfM) and Multi-View Stereo (MVS). Calibration is essential to achieve color accuracy and geometric precision, often requiring ground control points measured with a total station. 360° cameras are gaining popularity for quickly capturing comprehensive data, with applications in virtual tours and 3D reconstruction. Affordable cameras can create virtual tours, but high-quality 3D reconstruction needs specialized cameras with arrays of sensors. The most common setup features are two back-to-back image sensors with 180° lenses, while advanced models use 3 to 25 sensors to minimize distortion and enhance resolution, crucial for effective 3D reconstruction.

Terrestrial Laser Scanners

LiDAR technology in Terrestrial Laser Scanners (TLS) uses active sensors that emit laser beams in the 900–1064 nm wavelength range. These beams reflect off nearby objects, allowing the scanner to measure the distance through time of flight (TOF) or phase shift. Modern TLS devices can capture a 360° × 270° field of view and acquire points at rates from 30,000 to 2 million points per second. Key TLS characteristics include angular resolution, distance accuracy, signal-to-noise ratio, and the presence of a coaxial RGB camera. The final point accuracy typically ranges from 5 to 15 mm at 100 meters. During post-processing, point clouds undergo co-registration or geo-registration, often using spherical targets and combining total stations with Global Navigation Satellite Systems (GNSS). Iterative Closest Point (ICP) algorithms are employed for alignment. Many TLS units also incorporate complementary sensors like GNSS and barometers to improve initial positioning. Some modern systems use LiDAR or visual Simultaneous Localization and Mapping (SLAM) techniques for co-registration, allowing for mobility during data acquisition. Scanners can be handheld, vehicle-mounted, or drone-mounted, enabling faster data collection, although this may result in lower accuracy, typically between 30 mm and 50 mm at 100 meters. Regular professional calibration and servicing are crucial for maintaining the performance of these complex instruments.

5.2 Low-Altitude Sensors

Drones use similar sensors for low-altitude applications, with onboard RGB sensors that enable better photography positions and angles. The introduction of location-aware drones with single-frequency GNSS in the early 2010s led to autonomous flights for large-scale mapping. Subsequently, multicopter drones captured oblique photographs for detailed 3D reconstructions of cultural heritage sites.

Onboard cameras are optimized for weight and space but resemble standard cameras. The adjustable flying height allows for control over image scale without needing interchangeable lenses, with wide-angle lenses preferred for their favorable base-to-height ratio and height precision.

Manufacturers prioritize small, lightweight cameras, often custom-made without extra accessories. While cameras and drones are technically separate, many vendors have created combined solutions that limit user choices. Some drones offer various payload options, including RGB, thermal, multispectral, hyperspectral, and LiDAR sensors, but these cater to specialized applications.

5.3 Underwater Sensors

Underwater RGB sensors function passively but become active with flash or artificial lighting. Natural sunlight decreases with depth, making it difficult to capture clear photos without external light. Additionally, water absorbs infrared, red, and green wavelengths, resulting in a predominant blue hue, which complicates color accuracy despite using color checkers. This variability in light attenuation depends on environmental factors and the distance from the light source to the subject.

This leads to significant color differences in underwater images, prompting ongoing research into haze removal and color restoration techniques, although no universal solution exists. When a camera is in a watertight enclosure, light passes through multiple media, invalidating the principle of straight light transmission. If the camera is properly aligned, geometric image deformations can be corrected with existing lens distortion models and through self-calibration.

Dome ports are more effective than flat ports, which can introduce additional deformation, such as color aberration. The advent of Structure from Motion (SfM) and Multi-View Stereo (MVS) techniques has led to the development of various applications for documenting underwater heritage. Recently, efforts have been undertaken to address the challenge of color degradation in deep waters under artificial lighting conditions [12]. The authors introduced an initial solution to the significant loss of color in these environments using a self-adaptive color calibration method. This approach is independent of physical and environmental parameters and incorporates Structure from Motion (SfM), Multi-View Stereo (MVS), and Fast Nearest Neighbor (FNN) techniques.

5.4 Aerial and Satellite Sensors

Aerial and satellite sensors have become essential tools for studying cultural heritage. Aerial photogrammetry, one of the oldest methods for surveying extensive archaeological sites and heritage objects, has proven valuable in this field. Archived aerial images are particularly significant, as they provide important information about landscapes that have changed due to modern construction.

In recent years, the use of sensors on satellite platforms has also increased significantly. This growth is primarily due to advancements in the space sector, which have enhanced the capabilities of these satellites to deliver improved spatial and spectral imagery. Contemporary satellites can capture multispectral and hyperspectral data across a range of approximately 380 nm to 2500 nm, and thermal sensors with resolutions as high as 5 meters are now available.

6 Discussion

This paper envisions to promote research potentials towards the better protection, management, and documentation of cultural heritage sites of Cyprus. CUT's projects pathways to impact involve supporting emerging multidisciplinary needs for monitoring, documenting, analyzing, and preserving cultural heritage sites on land and underwater. The project's expected results include:

- knowledge in data collection and integration in cultural heritage,
- implementing a cloud Data Centre,
- developing geospatial fusion techniques and creating databases and datasets of cultural heritage sites.

Additionally, the project aims to implement security measures, establish guidelines for standards, and train researchers. A Communication, Dissemination, and Exploitation plan will support the project outcomes. These projects focus on reaching academia, the research community, professionals, private industry, stakeholders, public authorities, and the public interested in innovative technologies, research, cultural heritage, and schools. The preliminary outcomes highlight the potential of the infrastructure, making it open to external users and potential collaborators. Innovative technologies for heritage documentation can impact a range of economic, social, and technological developments.

By utilizing these innovative technologies for heritage documentation, we will enhance public awareness and appreciation of cultural heritage while facilitating knowledge sharing and cultural exchange. Technological advancements will include linking cloud data centers and showcasing innovative methods for documenting cultural heritage. This is expected to lead to breakthroughs in computer vision, machine learning, and robotics, resulting in the development of new tools and software. These technologies can also create new applications in urban planning, architecture, and geospatial analysis.

Also, the project seeks to promote innovative technologies for heritage documentation, offering businesses opportunities to develop and market innovative products and services, such as virtual tours and online education programs. Finally, the ongoing projects can have a positive environmental impact by reducing the need for on-site visits and traditional surveying methods, which generate carbon emissions.

Acknowledgments: The authors acknowledge the ENGINEER. This project has received funding from the European Union’s Horizon Europe Framework Programme (HORIZON-WIDERA-2021-ACCESS-03, Twinning Call) under grant agreement no. 101079377 and the UKRI under project number 10050486. In addition, the authors would like to thank the CONNECTING project. This project has received funding from the European Regional Development Fund and the Republic of Cyprus through the Research and Innovation Foundation of Cyprus under contract SMALL SCALE INFRASTRUCTURES/1222/0062.

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