GEOMATICS AND CIVIL ENGINEERING INNOVATIVE RESEARCH ON HERITAGE: INTRODUCING THE "ENGINEER" PROJECT

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ABSTRACT:

This paper aims to introduce the concept and objectives of a recently supported European project entitled "Geomatics and Civil Engineering Innovative Research on Heritage", in short ENGINEER. The ENGINEER project visions to enhance and extend inter-departmental multidisciplinary research activities of the Department of Civil Engineering & Geomatics of the Cyprus University of Technology through coordination and support actions as well as through targeted research activities with the support of European leading institutions. Project 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 ancient monuments and cultural heritage sites, assisting their protection, promotion, and safeguarding.

1. INTRODUCTION

Cultural heritage in the Mediterranean region faces numerous natural and anthropogenic threats (including climate change effects) (Agapiou et al., 2020; Sesana et al., 2021). In addition, financial limitations require innovative multidisciplinary solutions that can currently enhance techniques and methods used for better appreciation, protection, and monitoring of heritage sites.

Therefore, it is important to promote heritage research, to eliminate the risk of destruction of monuments and sites through the development of common standards and methodologies coupled with up-to-date technologies, like non-contact sensors in the field of geomatics, blended with structural analysis and conservation engineering. These can act as early warning signals for endangered monuments and contribute to their preservation and protection.

ENGINEER's idea ("ENGINEER," n.d.) is built around EU policies and international conventions related to cultural heritage protection, management and best practices (e.g. Europa Nostra policy documents; COM (2014) 477; UNESCO and EU conventions and multilateral treaties) ("Documents – ICOMOS International Scientific Committee on Archaeological Heritage Management," n.d., "Publications - Europa Nostra," n.d.; European Commission, 2014). The use of novel documentation geomatic technologies, like close-range photogrammetry and laser scanners, has progressively been established in environmental monitoring. In the domain of cultural heritage and landscape, particularly regarding archaeological sites and monuments, these technologies have significantly contributed to research and analysis over the past few decades (Armesto et al., 2008; Bariami et al., 2012; Bezas et al., 2020). The potential use of geomatics technologies for the understanding, documentation, monitoring and valorisation of cultural heritage has long been recognised not only by engineers and archaeologists but also by the public authorities involved in heritage management, which suggested an increasing use of non-invasive technologies ("Convention for the Protection of the Archaeological Heritage of Europe (revised) (Valletta, 1992) - Culture and Cultural Heritage," n.d.). These benefits are also significant for policies and management of vast portions of territory, such as the European Landscape Convention ("Council of Europe Landscape Convention / Official website - Council of Europe Landscape Convention," n.d.).

To fulfil ENGINEER's vision, the Cyprus University of Technology (CUT) is collaborating with three leading European Institutes, namely the Politechnic University of Milan (POLIMI), the University College London (UCL) and the University of Aveiro (UAVEIRO). The participants are expected to work closely with their local teams through targeted training research activities, mobility actions networking and in situ pilot applications. Simultaneously, the leading institutions will support CUT to advance research management, administrative skills and to promote industrial and knowledge transfer, thus reforming its Research and Innovation (R&I) system. The participation of the Eratosthenes Centre of Excellence (ECoE) aims to amplify the impact of ENGINEER by creating strong

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bonds with partners and will support commercialization and marketed aspects.

2. RESEARCH GAPS AND END-USERS NEEDS

Understanding the nature of the captured data is essential in making them effective for a given conservation outcome and meeting end-user data requirements with the appropriate (and affordable) geomatic methods. In addition, issues still arise concerning the potential multi-use of data that need to meet standards, the collaboration for multi-disciplinary projects and rigorous specifications to meet the expectations of the policy makers and users. Moreover, concerns are related to the data integration and interdisciplinary use of digital techniques, making the right choices on workflow and data flexibility. Finally, data from different sources can be used in different ways, and each way allows different integration paths with other techniques; while data types (and standards) can guarantee maximal data reuse, the risks and benefits of a given technique can be understood.

The ENGINEER project aims to bridge some of these gaps between the geomatic and civil engineering through targeted (common) training and research activities. Lesson learned from these activities can pave the road for future activities towards a more detailed and holistic understanding of monument threats and approaches for safeguarding.

3. TRAINING ACTIVITIES

Towards this direction, the CUT team has aligned forces with three leading European institutions, POLIMI, UCL and UAVEIRO, as mentioned previously. These leading teams will work closely with the local team through targeted training and research activities, mobility actions, networking, and in situ pilot applications.

In specific POLIMI will contribute to strengthen capabilities of CUT staff in the domain of geomatics applied on built environment and with a focus on cultural heritage and cultural landscapes, including advanced surveying and monitoring, high level design and representation of heritage, Historic BIM development and visualisation techniques. Furthermore, POLIMI will expose to the personnel of CUT a broad multidisciplinary view of the engineering world, encompassing engineering resilience to natural hazards and climate change, to structural preservation of iconic heritage sites. In more detail, the advanced partners will train the CUT colleagues in state-of-the-art experimental research, exploiting unique experimental infrastructure, which can accommodate large-scale testing for masonry wall specimens and other large structural element under monotonic and low-frequency cyclic loading, capable of producing full-scale experiments on various types of masonry material under different loading and environmental conditions.

The UCL entails two environmental chambers that enclose a reaction-frame where lateral and vertical cyclic loading can be applied. This set-up allows environmental conditioning of the specimens, including differential hygrothermal conditions simulating external and internal environment, together with simulation of wind driven rain, submersion by flooding and lateral dynamic loading, such as wind loading. The proposed activities will allow to train the CUT staff in a broad range of procedures relevant to the protection and conservation of heritage structures.

UAVEIRO will contribute to strengthen research capacity in multidisciplinary R&D activities, strongly linked with ongoing interventions in monuments, urban built heritage, and archaeological sites, providing expertise on building assessment, materials and decay characterization, seismic and structural technical reports, consultancy to ongoing conservation interventions in built heritage with monitoring. These proposed activities will allow to train the CUT staff in a high number of in-situ and laboratory activities relevant for assessment and monitoring of heritage for purposes of conservation and resilience to natural risks of cultural heritage, such as monuments, archaeological sites and urban built heritage.

At the same time, the previously mentioned leading institutions will advance research management and administrative skills, as well as they will promote industrial and knowledge transfer to the CUT, with the ultimate scope to reform CUT's Research and Innovation (R&I) system, in the tagged fields. The participation of the ECoE will multiply the potential impact of the project, creating strong links with partners of the quadruple helix of the Smart Specialization strategy, and will support commercialization and marketed aspects.

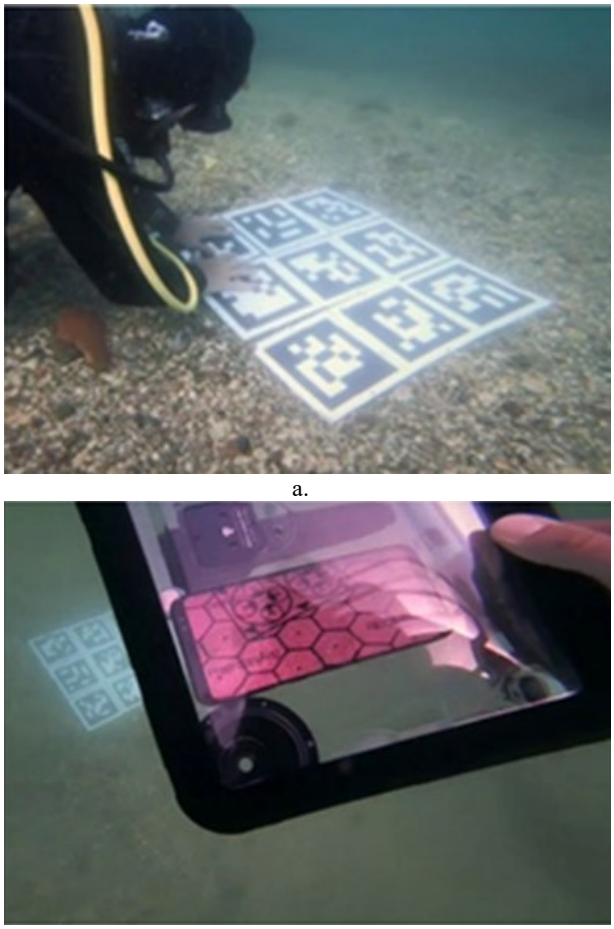
4. MOTIVATION FROM PREVIOUS EXAMPLES

Smart Specialization Strategy of Cyprus was designed to pave the wave for future sustainable development of the country, capitalizing on its unique characteristics and research ecosystem. The strategy final report puts cultural heritage at the heart of the country's future development as a horizontal pillar, whereas other disciplines such as tourism – the main economic revenue stream of the country – and ICT potentially interrelate (Bertini et al., 2013).

In terms of economic policy, cultural heritage in Cyprus has generally been considered as a cost to society, a financial burden tolerated, principally, as a moral duty. Museums, ancient monuments, historic buildings, and cultural landscapes have been maintained at public cost - as places that have not directly generated measurable economic growth. It is now generally accepted that neglecting natural and cultural environments can have severe economic and social impacts which outweigh the cost of their protection and valorisation. As a result, environmental considerations are often mainstreamed into policy and are an integral part of overall economic models.

Indeed, recent studies and examples around Europe and elsewhere have shown that heritage can boost the real economy, especially through new concepts of tourism (cultural tourism, geotourism, sustainable tourism), as well as for the construction industry (heritage buildings, etc.).

A recent example from iMARECULTURE project, which was awarded as the H2020 Cultural Heritage project with Outstanding Contribution to Sustainable Development, demonstrates that cultural heritage research can produce sustainable results. The development of an underwater AR tablet, which is being used both for navigation in an underwater cultural heritage site and provide AR 3D information about a roman villa (Bruno et al., 2019), is an excellent example of tools which were adopted in many other Innovation Actions of H2020 and local applied research projects (Figure 1). In fact, results from iMARECULTURE were adopted in other projects such as the BLUEMED, LAB4DIVE, DiveSafe, MeDryDive, ScienceDIVER, CREAMARE, and TECTONIC.



a. b.

Figure 1. Underwater AR in iMARECULTURE (from Bruno et al., 2019)

The development of novel methodologies for long term monitoring of heritage monuments and the prevision of upcoming adverse hazardous effects (i.e., climate change, earthquakes), will cost much less (in monetary terms) to advent the impact of these phenomena. In societal terms losing a monument has no remedy, hence the digital documentation of these monuments is crucial in order to preserve the monument's state prior to any effect and to mitigate the impact of such effects long term. The project actions aim to contribute to standards' setting for long term monitoring of built heritage.

A preliminary study for monitoring underground heritage site was carried out in the past by the authors. In specific, the correlation of the damage condition with historical seismic activity has been tested for tomb T4 from the Tombs of the 'Kings' necropolis, a UNESCO world heritage site (Kyriakides et al., 2017). Moreover, a simulation study was conducted with a real record from a similar seismotectonic environment which was amplified up to the level of the anticipated hazard in the area (Figure 2).

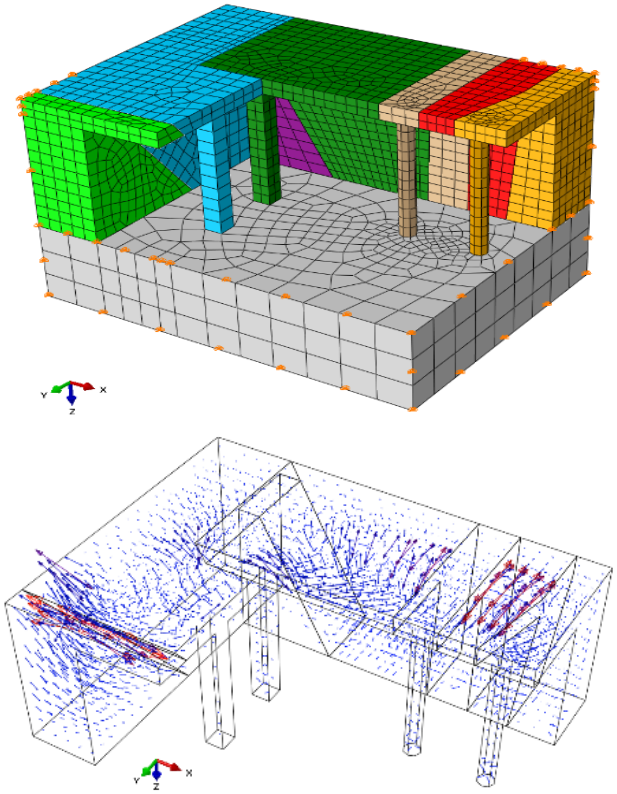


Figure 2. Top: 3D FE model developed for examining the seismic behaviour of the T4 tomb. Interacting stone blocks separated by cracks are shown in different colors. Bottom: Tensor diagram showing the computed distribution of the maximum principal stresses when the peak ground acceleration is imposed (from Kyriakides et al., 2017).

5. PROJECT OBJECTIVES

The ENGINEER objective is built upon the unique (national) character, of the Department of Civil Engineering and Geomatics of CUT, as the only University Department in Cyprus where civil and geomatic engineers come together. The ENGINEER twinning project visions fulfil and extend inter-departmental research activities using cultural heritage as the research domain.

The project is expected to significantly strengthen the scientific excellence and innovation capacity and improve research potentials of active research labs operating within the CUT. At the same time, targeted research actions and excellence paradigms, guided by the leading institutions (POLIMI, UCL and UAVEIRO), are expected to raise the CUT reputation significantly.

5.1 Scientific and Technological (S&T) Objectives

Project's objectives are considered both measurable and verifiable as they are linked with specific actions (WPs and Tasks) and project's deliverables, while based on the expertise and capacity of the leading institutions (POLIMI, UCL and UAVEIRO), these are considered realistically achievable. In specific, the following Scientific and Technological Objectives, as well as Training and Knowledge transfer Objectives, that will be fulfilled by the end of the project through seven work packages, are presented below.

First is the enhancement of the scientific excellence of CUT in the fields of data acquisition and processing, state of the art close-

range photogrammetric techniques, digital twins of heritage sites and monuments, 3D modelling, visualization, Historic Building Information Management (HBIM), non-contact sensors, structural dynamics, structural health monitoring of heritage sites, advanced numerical modelling, integrated structural and environmental testing, strengthening, upgrading and repair methods for heritage structures, and mitigation of climate change effects.

Following the above, the intensive, high-quality training of the research staff currently working at CUT in new acquisition technologies, management systems, tools and methods for cultural heritage sites and monuments, is another crucial S&T objective.

Additionally, one of the goals of the project, is to raise CUT staff research profiles of all levels (R1-R4) through joint publications and conference attendance. On top of that, the project aims to raise the reputation of CUT, providing evidence for the excellence and contribution of ENGINEER through a joint application for the EU prize for cultural heritage, namely the Europa Nostra Award ("Homepage - Europa Nostra," n.d.).

Furthermore, is the advancement of CUT's multidisciplinary outlook by blending civil engineering, architecture and geomatics research activities, providing thus a holistic approach for heritage management and assessment of environmental impacts on monuments.

The project aims to create close ties between academic research and end-users/stakeholders, professionals and society related to cultural heritage sectors, counting the project's supporters (Department of Antiquities of Cyprus, Cyprus Scientific and Technical Chamber and Association of Civil Engineers of Cyprus) and others (e.g., ICOMOS Cyprus section). This objective will be achieved through the promotion and networking activities of the project.

Besides the academic advancements, ENGINEER seeks to build close ties with the private sector, including industries, regional cultural heritage entities and SMEs relating to commercialization of the results and marketed plans, advance Technology Readiness Levels (TRL) of services and products, boosting entrepreneurship, engaging also strategic partners of the ECoE network.

The objectives of CUT and Smart Specialisation Strategy for Cyprus (S3Cy) are also aligned with other European initiatives and directives (including those of ERA Destination "Improved access to excellence" and advance Digital Transition, UN Sustainable Development Goals, national & EU Recovery and Resilience Facility investments), towards cultural heritage preservation and management.

Another important objective of the project, is the provision of training and guidance to CUT colleagues to attract research funding through Horizon Europe and other research funding pools, joined with leading institutions in Europe like those of UCL, POLIMI and UAVEIRO, even beyond the end of the project.

Finally, ENGINEER will provide guidance to reform the R&I system of the CUT to increase attractiveness and retention of research talents by simplifying procedures, becoming more transparent and adopting gender equality plans.

5.2 Training and Knowledge transfer (T&K) Objectives

As part of T&K objectives, ENGINEER will enhance training of scientists in novel techniques and digital technologies, management information data systems, and best practices in cultural heritage. This will be achieved by accomplishing various training meetings such as joint summer schools, workshops, seminars etc., provided by the UAVEIRO, POLIMI and UCL partners, with the support of ECoE for increasing TRLs of research outcomes.

Also, another objective is the strengthening of the state-of-art multidisciplinary character of the CUT in aspects of integrated geomatics-civil engineering approaches in cultural heritage risk evaluation, conservation, documentation and digitization and its transformation to a transnational access point in the eastern Mediterranean.

The leading institutions will provide and support transnational access to CUT members to infrastructures, strengthening high-quality collaboration in and outside the EU. The existing infrastructure of the POLIMI, UCL and UAVEIRO institutions will be used for the project's tasks. At the same time, networking activities will map regional infrastructure facilities that can support future collaborative research.

Lastly, the project will reinforce research management and administration skills of the CUT members, providing thus the necessary flexibility and support for further research growth of the coordinating institution.

6. OVERALL APPROACH

The project's approach involves partners of the quadruple helix of future growth of the Smart Specialization of Cyprus (and Europe), namely parties from the Research and Academia, Stakeholders and Policy Makers, the Private Sector, and actors from the Society, as shown in the last column of Figure 3. The entities will be engaged from the early stage of the research actions with participation in the CSA training events and knowledge transfer.

ENGINEER will use the full range of the WIDERA Twinning call's support measures, maximizing the outcomes' impact by continuous interaction with the three leading institutions (POLIMI, UCL and UAVEIRO). The proposed methodology (Figure 3) includes the following five steps:

- Step 1: Position the CUT in terms of research, excellence and context.
- Step 2: Training and educational actions.
- Step 3: Mobility, Networking and Knowledge Transfer.
- Step 4: Research actions
- Step 5: Reforming the R&I system of the CUT.

The details for each step are provided below:

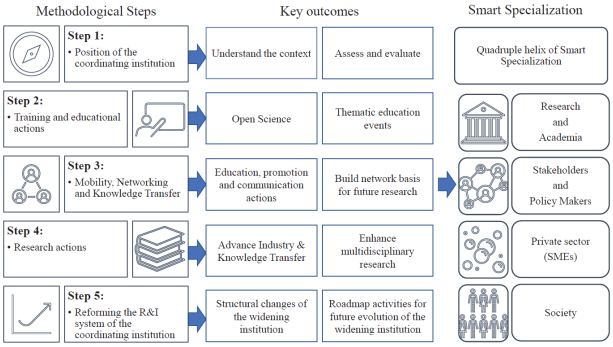


Figure 3: The methodological steps of ENGINEER

- Step 1: Position of the coordinating institution: It includes all actions that will take place to "map" the existing capacity of the CUT in its local, regional, and European context. A gap analysis has been carried out as desk-based research with the leading institutes analysing the following parameters: research profile, existing infrastructure capacity, equipment and software, links with the industry, society, private and public sector, academic reputation. Step 1 was executed at the beginning of the project. Actions were led by the advance partners that "analysed" CUT's profile at all levels, understanding, therefore, its research excellence, capacity, potentials, and gaps. This analysis will be further used to support the project's training, mobility and research actions (Steps 2-4) and the measures for reforming the R&I system of the CUT (Step 5).

- Step 2: Training and educational actions: It compiles a series of targeted training and educational activities that will take place during the project. The leading institutions (UAVEIRO, POLIMI and UCL) will provide the training activities either separately, enhancing thus intradisciplinary research (i.e., per research group of the widening partner-CUT) or jointly, developing thus the multidisciplinary character of the CUT as a whole. Training and education activities include thematic workshops, summer schools, hands-on experience and demonstrations in software and equipment, and virtual training. In addition, it is expected that the members of the widening institution (CUT) will have a "follow-up" after the training with the leading institutions for "digestion" of the new knowledge. Finally, management and administrative skills are expected to support future research activities of the CUT through targeted training events.

- Step 3: Mobility, Networking and Knowledge Transfer: Step 3, which will run in parallel with Step 2, includes internal consortium mobility actions. This is necessary for CUT to visit and utilize the leading institutions' facilities and infrastructures. In addition, mobility actions will provide the basis for networking with regional and European partners supported also by the communication and outreach activities of the project. The latest includes among others joint publications at impact factor open access journals and international conferences, co-authored by CUT researchers and colleagues from the POLIMI, UCL and UAVEIRO. "Industry & Knowledge Transfer" skills are also expected to be channelled from the advanced partners (POLIMI, UCL and UAVEIRO) to CUT members. These actions will be sustained by the ECoE, with complementary skills such as co-operation with industry, intellectual property rights (IPRs), spinoff operations and entrepreneurship.

- Step 4: Research actions: Actions listed under Step 4 aim to advance CUT's research agenda. Step 4 includes research activities jointly implemented between the advance partners and the coordinating institution. These activities will be materialised in WP6 under the form of specific research / scientific projects. These research activities will further strengthen the impact of the previous steps, namely the "Training and educational" (Step 2) and "Mobility, Networking and Knowledge Transfer" (Step 3) to the CUT.

- Step 5: Reforming the R&I system of the coordinating institution: The final step is focused on actions and suggestions to the CUT from the leading partners, for structural changes to reinforce the R&I ecosystem. The long-term collaboration with the leading institutions, during the 3-years of the project, is expected to change the CUT's nature of innovative future research with tangible goals for both the researchers and the society. Several other improvements for other aspects, including gender issues, gender balance in research, the attraction of high and early-stage researchers, are expected as well. The final step also includes actions to be taken by the consortium beyond the duration of the ENGINEER project (such as joint research agenda, exchange of personnel by other funded schemes etc.). The extensive documentation of the above will be the basis of a future roadmap of actions that will capitalize on the project's experience.

7. CONCLUSIONS

The project envisions to promote research potentials towards the better protection, management, and documentation of cultural heritage sites, assisting thus the local stakeholders of ENGINEER and the responsible authority for the cultural heritage of Cyprus to meet their goals. At the same time, it is expected to support engineers, SMEs, and policy makers to promote innovative solutions and state of the art engineering approaches for heritage management. With the inclusion of ECoE, a non-profit organization, the overall outcomes can have a real economic impact to the local society, through the exploitation of the ECoE digital innovation hub, providing the floor for potential spin-off companies, marketed solutions, patents etc. This can support sustainability after the end of the project.

Due to the multidisciplinary nature of the research, it is expected that diversified career guidance will be provided dealing with cultural heritage studies and vice versa, creating thus new growth prospects for the local economy. A critical mass of new researchers taking into consideration gender balance, will be formed in the field of geomatics and civil engineering, using advanced technologies.

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