ATHENA
Remote Sensing Science
Center for Cultural Heritage

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Project full title:	Remote Sensing Science Center for Cultural Heritage
Project acronym:	ATHENA
Work Package	WP6
Deliverable	D6.6: 7 conference papers

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Contributor(s):	**Rosa Lasaponara, Nicola Masini, Thomas Krauss, Gunter Schreier**	
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PU	Public	√
CO	Confidential, only for members of the consortium (including the Agency Services)	□

Document Sign-off				
Nature	**Name**	**Role**	**Partner**	**Date**
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			Period	**Type***
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1 Introduction

The Deliverable 6.6 with the title “7 conference papers”, is part of WP6 “Dissemination and Exploitation” of Athena project with a basic aim to knowledge sharing, network development and exposure to an international environment. Three conference attendances were foreseen (e.g. CAA; SPIE; EARSeL) within the project duration whereas more than 30 posters and oral presentations were presented during the project in the conferences such as: SPIE 2016, SPIE 2018, EUROMED 2016, EUROMED 2018, EGU 2016, EGU 2017, EGU 2018, RSCy2016, RSCy 2017, RSCy 2018, etc.

2 Title of papers presented during 3 years of ATHENA project

2.1 Papers - Oral Presentations

1. Capitalize on the Experience of the ATHENA Project for Cultural Heritage for the Eratosthenes Centre of Excellence for the Benefit of the East Med Region, Hadjimitsis D. G., Themistocleous K., Evagorou E., Michaelides S., Christofe A., Nisantzi A., Neocleoys K., Papoutsa C., Mettas C., Tzouvaras M., Loulli E., Kouta G., Danezis C., Lasaponara R., Masini N., Cerra D., Schreier G. and Papadavis G., 7th International Conference, EuroMed 2018, Nicosia, Cyprus, October 29–November 3 - In book: Digital Heritage. Progress in Cultural Heritage: Documentation, Preservation, and Protection - DOI: 10.1007/978-3-030-01762-0_56.
2. Remote sensing archaeology knowledge transfer: examples from the ATHENA twinning project, Hadjimitsis D. G., Agapiou A., Lysandrou V., Nisantzi A., Christofe A., Tzouvaras M., Papoutsa C., Mamouri R.E., Mettas C., Evagorou E., Themistocleous K., Papageorgiou N., Lasaponara R., Masini N., Biscione M., Danese M., Sileo M., Krauss T., Cerra Gessner U., Schreier G. and Michaelides S., Remote Sensing Technologies and Applications in Urban Environments - SPIE Remote Sensing 2018, Berlin, Germany - DOI: 10.1117/12.2325532.
3. Monitoring cultural heritage sites affected by geohazards, Themistocleous K and C. Danezis, Earth Resources and Environmental Remote Sensing/GIS Applications - SPIE Remote Sensing 2018, Berlin, Germany - DOI: 10.1117/12.2325455.
4. Digitization issues in documenting cultural heritage with drones: case study of Foinikas, Cyprus - Conference: Earth Resources and Environmental Remote

Sensing/GIS Applications - SPIE Remote Sensing 2018, Berlin, Germany - DOI: 10.1117/12.2325459

5. The innovative documentation of cultural heritage using H-BIM: case study of Asinou church, Themistocleous K., Earth Resources and Environmental Remote Sensing/GIS Applications - SPIE Remote Sensing 2018, Berlin, Germany - DOI: 10.1117/12.2325453
6. Study of ancient monuments' seismic performance based on Passive and Remote Techniques, Kyriakides N., Illampas R., Lysandrou V., Agapiou A., Masini N., Sileo M., Catapano I., Gennarelli G., Lasaponara R., Soldovieri F., Hadjimitsis D. G., 16th European Conference on Earthquake Engineering (16ECEE), 18-21, June, 2018, Thessaloniki, Greece.
7. From space to ground. Digital techniques or the investigation of monuments and sites, 10th MONUBASIN "Natural and Anthropogenic Hazards and Sustainable Preservation", Lysandrou V., Agapiou A., Kyriakides N., Hadjimitsis D. G., , 20-22 September 2017, Athens, Greece.
8. Benefits derived from "ATHENA" Horizon 2020 Twinning project in the field of Remote Sensing for Cultural Heritage, Hadjimitsis D.G., Agapiou A., Lyssandrou V., Nisantzi A., Christofe A., Tzouvaras M., Papoutsa C., Mamouri R., Mettas C., Evagorou E., Themistocleous K.,. EUROMED 2017, pp 727-731.
9. ATHENA: Center of Excellence in Cyprus in the Field of Remote Sensing for Cultural Heritage in the Areas of Archaeology and Cultural Heritage, Hadjimitsis D. G., Agapiou A., Lysandrou V., Branka C., Themistocleous K., Nisantzi A., Lasaponara R., Masini N., Krauss T., Cerra D., Gessner U., Schreier G., 6th GEOBIA 2016, 14-16 September 2016 / Enschede, The Netherlands.
10. Satellite based investigation for detection of ancient tombs' looting in Cyprus, Agapiou A., Lysandrou V., 2nd Computer Applications and Quantitative Methods in Archaeology (CAA GR) 2016, Athens, Greece 20-21 December 2016.
11. Observing the changes in landscape around the historical capital of Nicosia using multi-spectral multi-temporal datasets Cuca B., Agapiou A., Hadjimitsis D.G., 6th International Euro-Mediterranean Conference (EuroMed 2016), 31 Oct. – 05 November 2016, Nicosia, Cyprus.
12. Searching data for supporting archaeolandscapes in Cyprus: an overview of aerial, satellite and cartographic datasets of the island, Agapiou A., V. Lysandrou, K. Themistocleous, B. Cuca, R. Lasaponara, N. Masini, T. Krauss, D. Cerra, U. Gessner, G. Schreier, D. Hadjimitsis, Fourth International Conference on Remote

Sensing and Geoinformation of the Environment (RSCy2016), 4-8 April, 2016, Cyprus.

13. Automatic damage detection for sensitive cultural heritage sites, Cerra D., Tian J., Lysandrou V., Plank S., XXIII ISPRS Congress 2016, 12-19 July, 2016, Prague.

2.2 Abstracts - Posters

1. Research and support for knowledge transfer in the ATHENA Twinning project: Remote sensing for cultural heritage, Hadjimitsis D. G., Agapiou A., Lysandrou V., Nisantzi A., Christofe A., Tzouvaras M., Papoutsa C., Mamouri R.-E., Mettas C., Evagorou E., Themistocleous K., Lasaponara R., Masini N., Danese M., Sileo M., Krauss T., Cerra D., Gessner U., Schreier G., GEOBIA 2018, Montpellier, France.
2. The use of Copernicus data to support archeological research in the Eastern Mediterannean, Hadjimitsis D. G., Christofe A., Agapiou A., Nisantzi A., ., Tzouvaras M., Papoutsa C., Mettas C., Evagorou E., Themistocleous K., Lysandrou V., Kouta G., Lasaponara R., Masini N., Schreier G., EARSEL 2018.
3. ATHENA project: training activities for the detection of looted archaeological sites, Hadjimitsis D. G., Christofe A., Agapiou A., Lysandrou V., Themistocleous K., Lasaponara R., Masini N.,Geophysical Research Abstracts, EGU2018, Vienna, Austria.
4. Knowledge transfer through the ATHENA Twinning project: Remote sensing for cultural heritage, Hadjimitsis D. G., Christofe A., Agapiou A., Lysandrou V., Nisantzi A., Tzouvaras M., Papoutsa C., Mamouri R.-E., Mettas C., Evagorou E., Themistocleous K., Lasaponara R., Masini N., Danese M., Sileo M., Krauss T., Cerra D., Gessner U., Schreier G., Geophysical Research Abstracts, EGU2018, Vienna, Austria.
5. Earth observation technologies and cultural heritage needs through the ATHENA TWINNING PROJECT", Hadjimitsis D. G., Agapiou A., Lysandrou V., Nisantzi A., Christofe A., Tzouvaras M., Papoutsa C., Mamouri R., Mettas C., Evagorou E., Themistocleous K., Lasaponara R., Masini N., Danese M., Sileo M., Krauss T., Cerra D., Gessner U., Schreier G., CAA 2018, 19-23 March 2018, Tubingen, Germany.
6. Exploring the Importance of Monitoring the Fire Risk Index in the vicinity of Cultural Heritage Sites in Cyprus using Sentinel Remote Sensing data, Kouhartsiouk D., Agapiou A., Lysandrou V., Themistocleous K., Nisantzi A., Hadjimitsis D. G.,

Lasaponara R., Masini N., Krauss T., Cerra D., Gessner U., 11th EARSeL Workshop, 25-27 September 2017 Chania, Crete.

7. Copernicus and Cultural Heritage in the Eastern Mediterranean under the 'ATHENA' Project, Agapiou A., Lysandrou V., Themistocleous, K.; Kouhartsiouk D., Nisantzi A., Cerra D., Gessner U., Krauss T., Shreier G., Lasaponara R., Masini N., Hadjimitsis D. G., RSPSoc 2017 Annual Conference Earth & Planets: making the most of our observations, 5th – 8th September 2017, Imperial College London, UK.
8. From Detection of Underground Archeological Relics to Monitoring of Word Heritage Sites in Danger: Ongoing Research Activities in the Frame of the ATHENA Twinning Project, Cerra D., Agapiou A., Plank S., Lysandrou V., Tian J., Schreier G., the 37th International Symposium on Remote Sensing of Environment -ISRSE 2017, 8-12 May 2017.
9. Exploitation of big data cloud infrastructures for earth observations: mapping the land use changes patterns in the vicinity of the Great Pyramid at Giza, Agapiou A., Fifth International Conference on Remote Sensing and Geo-information of the Environment 2017, 20-23 March, 2017, Cyprus.
10. Active Satellite Sensors for the needs of Cultural Heritage: Introducing SAR applications in Cyprus through ATHENA project, Kouhartsiouk D., Agapiou A., Lysandrou V., Themistocleous K., Nisantzi A., Hadjimitsis D. G., Lasaponara R., Masini N., Brcic R., Eineder M., Krauss T., Cerra D., Gessner U., Schreier G., Geophysical Research Abstracts Vol. 19, EGU2017, Vienna, Austria
11. Coastal archaeological sites and coastline changes: a multi-temporal GIS study based on aerial and satellite imageries in Cyprus, Agapiou A., Lysnadrou V., Zorpas E., Hadjimitsis D.G., Geophysical Research Abstracts Vol. 19, EGU2017, Vienna, Austria
12. Elaborating latent and apparent knowledge configurations in Hellenistic-and Roman landscape of Cyprus, Lysandrou V., Agapiou A., 2nd Computer Applications and Quantitative Methods in Archaeology (CAA GR) 2016, Athens, Greece 20-21 December 2016.
13. Urban landscapes: temporal changes around the historical capital of Nicosia, Cuca B., Agapiou A., Hadjimitsis D. G., Aerial Archaeology Research Group (AARG) annual meeting, Pilsen, Czech Republic, 7-9, September 2016.
14. ATHENA: Remote Sensing Science Center for Cultural Heritage in Cyprus. Hadjimitsis D. G., Agapiou A., Lysandrou V., Branka C., Themistocleous K.,

Lasaponara R., Masini N., Krauss T., Cerra D., Gessner U., Schreier G., European Geosciences Union – EGU, General Assembly 2016, 17 – 22 April 2016, Vienna, Austria.

15. Establishing a remote sensing science center in Cyprus: first year of activities of ATHENA project, Hadjimitsis D., Agapiou A., Lysandrou V., Themistocleous K., Lasaponara R., Masini N., Krauss T., Cerra D., Gessner U., Schreier G., 6th International Euro-Mediterranean Conference (EuroMed 2016), 31 Oct. – 05 November 2016, Nicosia, Cyprus.
16. Establishment of a center of excellence in the field of remote sensing for cultural heritage at the Cyprus university of technology: the 'ATHENA' Horizon 2020 Twinning project, Hadjimitsis D. G., Agapiou A., Lysandrou V., Branka C., Themistocleous K., Nisantzi A., Lasaponara R., Masini N., Krauss T., Cerra D., Gessner U., Schreier G., Fourth International Conference on Remote Sensing and Geoinformation of the Environment (RSCy2016), 4-8 April, 2016, Cyprus.
17. Educational activities of remote sensing archaeology, Hadjimitsis D. G., Agapiou A., Lysandrou V., Themistocleous K., Branka C., Nisantzi A., Lasaponara R., Masini N., Krauss T., Cerra D., Gessner U., Schreier G., (Conference Presentation), Proc. SPIE 10005, Earth Resources and Environmental Remote Sensing/GIS Applications VII, 100050L (December 9, 2016); doi:10.1117/12.2242109.
18. Orthogonal equations for the detection of archaeological traces de-mystified, Agapiou A., Fourth International Conference on Remote Sensing and Geoinformation of the Environment (RSCy2016), 4-8 April, 2016, Cyprus.

2.3 Books

ATHENA springer book (forthcoming)

Springer

Through the ATHENA project, the book "Remote Sensing for Archaeology and Cultural Landscapes" was prepared and is currently in print. The book is part of the "Springer Remote Sensing/Photogrammetry" book series, which is published by Springer.

The book provides an overview of the knowledge developed within the ATHENA project. The book is divided into four sections. The first section, Policy Perspective, examines the opportunities by the Copernicus Program for Archaeological Research and World Heritage

Site Conservation and policies related to Looting and Illegal Antiquities Trade, especially in light of the destruction of Palmyra, Syria. The second section, Advancements in Theory, focuses on various advancements in Earth observation techniques for archaeology, including the use of SAR, change detection from satellite imagery and Dense Surface Models from Airborne and Spaceborne (Multi-)Stereo Images. The third section, Archaeology and Cultural Landscapes focuses on case studies of how Earth observations techniques were used for different archaeological sites in different countries, such as Cyprus, Syria, Italy, Poland, etc. The forth section, Added Value of In-Situ Data, provided three case studies where in-situ data was used in combination with Earth observation techniques for monitoring archaeological sites in Palmyra, Syria, Petra, Jordan and Choirokoitia, Cyprus. The book provides detailed information regarding the value of the use of Earth observation techniques in archaeology and cultural heritage as well as the significance of the ATHENA project in terms of developing and applying these techniques.

3 Conferences where ATHENA was presented

ATHENA project presented in conferences relevant to the objectives of the project, focusing on the ATHENA's activities and outcomes. The conferences where ATHENA was presented, are following.

3.1 SPIE Remote Sensing (a) 26-29 September 2016, Edinburgh, UK and, (b) 10-13 September 2018, Berlin, Germany

Key concept:

SPIE, the international society for optics and photonics, was founded in 1955 to advance light-based technologies. Serving more than 264,000 constituents from approximately 166 countries, the not-for-profit society advances emerging technologies through interdisciplinary information exchange, continuing education, publications, patent precedent, and career and professional growth. SPIE annually organizes and sponsors approximately 25 major technical forums, exhibitions, and education programs in North America, Europe, Asia, and the South Pacific. SPIE Remote Sensing is an important European conference that includes atmospheric and earth surface sensing, next-generation satellites.

See more: http://spie.org/conferences-and-exhibitions/remote-sensing

Related Papers:

1. Remote sensing archaeology knowledge transfer: examples from the ATHENA twinning project, Hadjimitsis D. G., Agapiou A., Lysandrou V., Nisantzi A., Christofe A., Tzouvaras M., Papoutsa C., Mamouri R.E., Mettas C., Evagorou E., Themistocleous K., Papageorgiou N., Lasaponara R., Masini N., Biscione M., Danese M., Sileo M., Krauss T., Cerra Gessner U., Schreier G. and Michaelides S., Remote Sensing Technologies and Applications in Urban Environments - SPIE Remote Sensing 2018, Berlin, Germany - DOI: 10.1117/12.2325532.
2. Monitoring cultural heritage sites affected by geohazards, Themistocleous K and C. Danezis, Earth Resources and Environmental Remote Sensing/GIS Applications - SPIE Remote Sensing 2018, Berlin, Germany - DOI: 10.1117/12.2325455.
3. Digitization issues in documenting cultural heritage with drones: case study of Foinikas, Cyprus - Conference: Earth Resources and Environmental Remote

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5. Educational activities of remote sensing archaeology, Hadjimitsis D. G., Agapiou A., Lysandrou V., Themistocleous K., Branka C., Nisantzi A., Lasaponara R., Masini N., Krauss T., Cerra D., Gessner U., Schreier G., (Conference Presentation), Proc. SPIE 10005, Earth Resources and Environmental Remote Sensing/GIS Applications VII, 100050L (December 9, 2016); doi:10.1117/12.2242109.

3.2 EGU Geophysical Research (a)17-22 April 2016, (b) 23-28 April 2017 and, (c) 10-13 September 2018, Vienna, Austria

Key concept:

EGU, the European Geosciences Union, is Europe's premier geosciences union, dedicated to the pursuit of excellence in the Earth, planetary, and space sciences for the benefit of humanity, worldwide. It was established in September 2002 as a merger of the European Geophysical Society (EGS) and the European Union of Geosciences (EUG), and has headquarters in Munich, Germany. The EGU publishes a number of diverse scientific journals, which use an innovative open access format, and organises topical meetings, and education and outreach activities. It also honours scientists with a number of awards and medals. The annual EGU General Assembly is the largest and most prominent European geosciences event, attracting over 14,000 scientists from all over the world in recent years. The meeting's sessions cover a wide range of topics, including volcanology, planetary exploration, the Earth's internal structure and atmosphere, climate, as well as energy and resources. The EGU General Assembly brings together geoscientists from all over the world into one meeting covering all disciplines of the Earth, Planetary and Space Sciences. Especially for young scientists, it is the aim of the EGU to provide a forum where they can present their work and discuss their ideas with experts in all fields of geosciences.

See more: https://www.egu.eu/about/

Related Papers:

1. ATHENA project: training activities for the detection of looted archaeological sites, Hadjimitsis D. G., Christofe A., Agapiou A., Lysandrou V., Themistocleous K., Lasaponara R., Masini N.,Geophysical Research Abstracts, EGU2018, Vienna, Austria.
2. Knowledge transfer through the ATHENA Twinning project: Remote sensing for cultural heritage, Hadjimitsis D. G., Christofe A., Agapiou A., Lysandrou V., Nisantzi A., Tzouvaras M., Papoutsa C., Mamouri R.-E., Mettas C., Evagorou E., Themistocleous K., Lasaponara R., Masini N., Danese M., Sileo M., Krauss T., Cerra D., Gessner U., Schreier G., Geophysical Research Abstracts, EGU2018, Vienna, Austria.
3. Active Satellite Sensors for the needs of Cultural Heritage: Introducing SAR applications in Cyprus through ATHENA project, Kouhartsiouk D., Agapiou A., Lysandrou V., Themistocleous K., Nisantzi A., Hadjimitsis D. G., Lasaponara R., Masini N., Brcic R., Eineder M., Krauss T., Cerra D., Gessner U., Schreier G., Geophysical Research Abstracts Vol. 19, EGU2017, Vienna, Austria
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5. ATHENA: Remote Sensing Science Center for Cultural Heritage in Cyprus. Hadjimitsis D. G., Agapiou A., Lysandrou V., Branka C., Themistocleous K., Lasaponara R., Masini N., Krauss T., Cerra D., Gessner U., Schreier G., European Geosciences Union – EGU, General Assembly 2016, 17 – 22 April 2016, Vienna, Austria.

3.3 EUROMED (a) 31 October- 5 November 2016 and, (b) 29 October- 3 November 2018, Nicosia, Cyprus

Key concept:

Protecting, preserving and presenting our Cultural Heritage are frequently interpreted as change management and/or change the behavior of the society. Joint European and international research produces a scientific background and support for such a change. We are living in a period characterized by rapid and remarkable changes in the environment, in the society and in technology. Natural change, war conflicts and man-made changes, including climate, as well as technological and societal change, form an ever-moving and colorful stage and a challenge for the society. Close cooperation between professionals, the policy makers and authorities internationally, is necessary for research, development and technology in the field of cultural heritage. Scientific projects in the area of cultural heritage have received national, European Union or UNESCO funding for more than thirty years. Through the financial support and cooperation, major results have been achieved and published in peer-reviewed journals and conference proceedings with the support of professionals from many countries. The European Conferences on cultural heritage research and development and in particular the biannual EuroMed conference have become regular milestones on the never-ending journey of discovery in the search for new knowledge of our common history and its protection and preservation for the generations to come. They also provide a unique opportunity to present and review results, and to draw new inspiration. The agenda of this conference includes hundreds of excellent oral and poster presentations, as well as workshops and demonstrations from academia and industry, reflecting the wide scope of our work in the area of cultural heritage. We are expecting policy makers, professionals, students and delegates from more than 60 countries of the world to attend this special Euro-Mediterranean conference which is dedicated to the protection, preservation and e-documentation of the Cultural Heritage. The aim of EuroMed conference is to bring together as many stakeholders as possible from different backgrounds in order to achieve a high level of mutual understanding of the needs, the requirements and the technical means of meeting them. Therefore, our common goal is to focus on interdisciplinary and multi-disciplinary research on tangible and intangible Cultural Heritage, the use of cutting edge technologies for the protection, preservation, conservation, massive digitalisation and visualization/presentation of the Cultural Heritage content (archeological sites, artifacts, monuments, libraries, archives, museums, etc). At the same time, the event is intended to cover topics of research ready for exploitation, demonstrating the acceptability of new sustainable approaches and new technologies by the user community, SME's, owners, managers and conservators of cultural patrimony.

See more: https://www.euromed2018.eu/welcome

Related Papers:

1. Capitalize on the Experience of the ATHENA Project for Cultural Heritage for the Eratosthenes Centre of Excellence for the Benefit of the East Med Region, Hadjimitsis D. G., Themistocleous K., Evagorou E., Michaelides S., Christofe A., Nisantzi A.,

Neocleoys K., Papoutsa C., Mettas C., Tzouvaras M., Loulli E., Kouta G., Danezis C., Lasaponara R., Masini N., Cerra D., Schreier G. and Papadavis G., 7th International Conference, EuroMed 2018, Nicosia, Cyprus, October 29–November 3 - In book: Digital Heritage. Progress in Cultural Heritage: Documentation, Preservation, and Protection - DOI: 10.1007/978-3-030-01762-0_56.

2. Establishing a remote sensing science center in Cyprus: first year of activities of ATHENA project, Hadjimitsis D., Agapiou A., Lysandrou V., Themistocleous K., Lasaponara R., Masini N., Krauss T., Cerra D., Gessner U., Schreier G., 6th International Euro-Mediterranean Conference (EuroMed 2016), 31 Oct. – 05 November 2016, Nicosia, Cyprus.
3. Observing the changes in landscape around the historical capital of Nicosia using multi-spectral multi-temporal datasets Cuca B., Agapiou A., Hadjimitsis D.G., 6th International Euro-Mediterranean Conference (EuroMed 2016), 31 Oct. – 05 November 2016, Nicosia, Cyprus.

3.4 RSCY – International Conference on Remote Sensing and Geoinformation of Environment (a) 4-8 April 2016, (b) 20-23 March 2017 and, (c) 26-29 March 2018, Paphos, Cyprus

Key Concept:

The International Conference on Remote Sensing and Geoinformation comprises a significant conference gathering scientists in the field of Remote Sensing and Geo-information.

See more:
http://www.cyprusremotesensing.com/rscy2016/,
http://www.cyprusremotesensing.com/rscy2017/,
http://www.cyprusremotesensing.com/rscy2018/

Related Papers:

1. Exploitation of big data cloud infrastructures for earth observation cultural heritage applications: mapping the land use changes patterns in the vicinity of “the Great Pyramid at Giza”, Agapiou A., Fifth International Conference on Remote Sensing and Geoformation of Environment 20-23 March, 2017 – Cyprus.

2. Establishment of a center of excellence in the field of remote sensing for cultural heritage at the Cyprus university of technology: the 'ATHENA' Horizon 2020 Twinning project, Hadjimitsis D. G., Agapiou A., Lysandrou V., Branka C., Themistocleous K., Nisantzi A., Lasaponara R., Masini N., Krauss T., Cerra D., Gessner U., Schreier G., Fourth International Conference on Remote Sensing and Geoinformation of the Environment (RSCy2016), 4-8 April, 2016, Cyprus.
3. Orthogonal equations for the detection of archaeological traces de-mystified, Agapiou A., Fourth International Conference on Remote Sensing and Geoinformation of the Environment (RSCy2016), 4-8 April, 2016, Cyprus.
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5. Correlating damage condition with historical seismic activity in underground sepulchral monuments of Cyprus, Kyriakides N., Lysandrou V., Agapiou A., Illampas R., Fourth International Conference on Remote Sensing and Geoinformation of the Environment (RSCy2016), 4-8 April, 2016, Cyprus.

3.5 RSPSoc 2017: Annual Conference Earth & Planets: 5–8 September 2017, Imperial College London, UK

RSPSoc remote sensing & photogrammetry society

Key concept:

RSPSoc is the UK's leading Society for remote sensing and photogrammetry and their application to education, science, research, industry, commerce and the public service. As a charity, its remit is to inform and educate its members and the public. It supports networking between the university, business and government sectors. As an international society, RSPSoc is also active in Europe and on the world stage.

See more: http://www.rspsoc.org.uk/

Related Papers:

1. Copernicus and Cultural Heritage in the Eastern Mediterranean under the 'ATHENA' Project, Agapiou A., Lysandrou V., Themistocleous, K.; Kouhartsiouk D., Nisantzi A., Cerra D., Gessner U., Krauss T., Shreier G., Lasaponara R., Masini N., Hadjimitsis D. G., RSPSoc 2017 Annual Conference Earth & Planets: making the most of our observations, 5th – 8th September 2017, Imperial College London, UK.

3.6 CAA Computer Applications and Quantitative Methods in Archaeology, 20-21 December 2016, Athens, Greece

Key concept:

CAA is an international organisation bringing together archaeologists, mathematicians and computer scientists. Its aims are to encourage communication between these disciplines, to provide a survey of present work in the field and to stimulate discussion and future progress.

CAA organizes an annual international scientific conference, where practitioners can present their work in paper sessions, and discuss developments with colleagues from all over the world in round tables and workshops. The conference sessions cover a wide range of topics, including data acquisition and recording, conceptual modelling, semantic technologies, data analysis, data management, digital 3D object reconstruction, image visualisation in archaeology, geophysics and GIS.

See more: https://caa-international.org/

Related Papers:

1. Satellite based investigation for detection of ancient tombs' looting in Cyprus, Agapiou A., Lysandrou V., 2nd Computer Applications and Quantitative Methods in Archaeology (CAA GR) 2016, Athens, Greece 20-21 December 2016.
2. Elaborating latent and apparent knowledge configurations in Hellenistic-and Roman landscape of Cyprus, Lysandrou V., Agapiou A., 2nd Computer Applications and Quantitative Methods in Archaeology (CAA GR) 2016, Athens, Greece 20-21 December 2016.

3.7 16ECEE-16th European Conference on Earthquake Engineering, 18-21 June 2018, Thessaloniki, Greece

Key concept:

The European Conference on Earthquake Engineering, organized by the Aristotle University of Thessaloniki and cover areas like Large Scale Facilities for Earthquake Engineering purposes and Seismic Design and Analysis of Reinforced Concrete Buildings. In ECEE, earthquake, risk and geotechnical engineers, geologists and seismologists, young and experienced researchers from more than 60 countries across the world were presenting and discussing more than 1300 scientific papers, reflecting the progress made over the last few years in earthquake engineering. 16ECEE offer an excellent forum to exchange ideas, share knowledge and discuss the most recent advances, from engineering seismology and hazard to soil dynamics and geotechnical engineering, and from structural earthquake engineering to risk assessment, management, and seismic design guidelines developments.

See more: http://www.16ecee.org/

Related Papers:

1. Study of ancient monuments' seismic performance based on Passive and Remote Techniques, Kyriakides N., Illampas R., Lysandrou V., Agapiou A., Masini N., Sileo M., Catapano I., Gennarelli G., Lasaponara R., Soldovieri F., Hadjimitsis D. G., 16th European Conference on Earthquake Engineering (16ECEE), 18-21, June, 2018, Thessaloniki, Greece.

3.8 10th MONUBASIN "Natural and Anthropogenic Hazards and Sustainable Preservation", 20-22 September 2017, Athens, Greece

Key concept:

The International Symposium on the Conservation of Monuments in the Mediterranean Basin (MONUBASIN) has provided a forum for scientists, technicians and experts, in the area of conservation and restoration of monuments, to present their work and exchange ideas and experiences for over 28 years. The theme of this Symposium is "Natural and Anthropogenic

Hazards and Sustainable Preservation" and refers to the natural and anthropogenic hazards on monuments, as well as to the technologies used for damage rehabilitation in the direction of sustainable, long-lasting preservation. The Symposium addresses research work from restoration engineers, architects, geologists, restorers and conservators of stone artifacts and other specialists in the decay and restoration of monuments, as well as archaeologists, art historians and scientists in the fields of physics, chemistry and biology.

During the 10th Symposium, the Monubasin Digital Repository (MDR) will be presented to the participants. The MDR will offer access to all previous Symposiums' proceedings (more than 900 papers) providing various methods of search (e.g. full-text search, by author name, by paper title, by Symposium, etc.). All Symposium participants will have free access to the MDR contents.

See more: http://www.rspsoc.org.uk/

Related Papers:

1. From space to ground. Digital techniques or the investigation of monuments and sites, 10th MONUBASIN “Natural and Anthropogenic Hazards and Sustainable Preservation”, Lysandrou V., Agapiou A., Kyriakides N., Hadjimitsis D. G., , 20-22 September 2017, Athens, Greece.

3.9 ISRSE 2017-37th International Symposium on Remote Sensing of Environment, 8-12 May 2017, Tshwane, South Africa

Key concept:

International Symposium on Remote Sensing of Environment -ISRSE started in 1962 in Ann Arbor, Michigan, USA and is the world’s oldest remote sensing conference. It is currently convened on a biennial basis by the International Centre on Remote Sensing of Environment (ICRSE) and the International Committee on Remote Sensing of the Environment (ICORSE), a standing committee of the International Society of Photogrammetry and Remote Sensing (ISPRS).

ISRSE is widely acknowledged to be one of the most significant gatherings of the international remote sensing community. The Symposium attracts senior staff of space agencies and international Earth observation programmes and thereby provides a global overview of advances in Earth observation and the consequential societal benefits. The 2017 Symposium coincides with the implementation of the recently adopted African Space Policy and Strategy and rapid developments in African space science and technology programmes. This focus aims to leverage space science and technology to underpin economic and social development across the African continent. Earth observation presents a unique opportunity in Africa for cooperation, sharing and proactively managing, amongst others, disease outbreaks, natural resources and the environment, responses to natural hazards and disasters, agriculture and food security, weather forecasting and climate-change mitigation and adaptation. ISRSE-37 therefore intends to attract to it a significant numbers of remote sensing experts to exchange views on scientific results, new applications and major programmes. The Symposium also provides attendees an opportunity to explore Tshwane and South Africa’s unique natural and cultural heritage.

See more: https://events.sansa.org.za/2016-06-30-09-15-17

Related Papers:

1. From Detection of Underground Archaeological Relics to Monitoring of World Heritage Sites in Danger: Ongoing Research Activities in the Frame of the ATHENA Twinning Project, Cerra D., Agapiou A., Plank S., Lysandrou V., Tian J., Schreier G., 37th International Symposium on Remote Sensing of Environment, ISRSE 2017, 8-12 May 2017, South Africa.

3.10 ISPRS Congress, 12-19 July 2016, Prague, Czech Republic

Key concept:

ISPRS is a leading organization in remote sensing, photogrammetry and spatial information sciences - very high-resolution satellite imagery, terrain based imaging and participatory sensing, inexpensive platforms, and advanced information and communications technologies. Every 4 years the Congress welcomes participants from all over the world. This gathering strengthens relations among the researchers, professionals and representatives of governmental and non-governmental organization thus enhancing the co-operation within the field. ISPRS welcomes all papers bringing new results, achievements, methods and theory to help to shift the present level of knowledge. The program structure is split into several session types: Technical Sessions, Theme Sessions, Special sessions, Plenary Meetings, Exhibitor’s Showcase Sessions and Commercial Sessions.

See more: http://www.isprs2016-prague.com/

Related Papers:

1. Automatic damage detection for sensitive cultural heritage sites, Cerra D., Tian J., Lysandrou V., Plank S., XXIII ISPRS Congress 2016, 12-19 July, 2016, Prague.

3.11 AARG-Aerial Archaeology Research Group annual meeting, 7-9 September 2016, Pilsen, Czech Republic

Key concept:

The Aerial Archaeology Research Group (AARG) provides a forum for the exchange of ideas and information for all those actively involved in aerial photography, photo interpretation, field archaeology and landscape history. This also includes the use of aerial photography in defining preservation policies for archaeological sites and landscapes.

Since its foundation in 1983, AARG has actively encouraged such exchange through its annual conference, specialist meetings and, more recently, through the biannual publication of its newsletter, AARG news. The Group (AARG) holds its Annual Conference in Pilsen (Czech Republic). The meeting includes papers and posters, social events, and a field trip. Papers given at the AARG conference are grouped into themed sessions: (a) teaching aerial archaeology / teaching landscapes, (b)aerial archaeology of the recent past, (c) experiments, (d) aerial archaeology and art, (e) changing landscapes

See more: https://www.univie.ac.at/aarg/index.php

Related Papers:

1. Urban landscapes: temporal changes around the historical capital of Nicosia, Cuca B., Agapiou A., Hadjimitsis D. G., Aerial Archaeology Research Group (AARG) annual meeting, Pilsen, Czech Republic, 7-9, September 2016.

3.12 GEOBIA (a) 14-16 September 2016, Enscheda, Netherlands and, (b) 18-22 June 2018, Montpellier, France

Key concept:

During the last 10 years the GEOBIA community has grown from a niche discipline to a recognized and vibrant branch of geoinformation science, and methods developed by the growing community have helped to tackle problems in virtually all domains where geographic data are used. The growing importance of image processing, be it of traditional airborne or satellite data, but also complex hyperspectral data stacks, videos, or image data used by other communities (e.g., bio-medical and pharmaceutical), has resulted in a multitude of methodological approaches. Segmentation-based approaches have turned out to be an excellent way to incorporate process and feature knowledge, in addition to providing an effective way of dealing with multi-scale data. As a consequence hundreds of scientific publications have greatly enriched the geoinformation science domain over the past decade.

See more: https://www.geobia2016.com/ , https://www.geobia2018.com/

Related Papers:

1. ATHENA: Center of Excellence in Cyprus in the Field of Remote Sensing for Cultural Heritage in the Areas of Archaeology and Cultural Heritage, Hadjimitsis D. G., Agapiou A., Lysandrou V., Branka C., Themistocleous K., Nisantzi A., Lasaponara R., Masini N., Krauss T., Cerra D., Gessner U., Schreier G., 6th GEOBIA 2016, 14-16 September 2016 / Enschede, The Netherlands.

3.13 EARSeL (a) 25-27 September 2017 and, (b) 13-14 July 2018 Chania, Crete

EARSeL | EUROPEAN ASSOCIATION OF REMOTE SENSING LABORATORIES

Key concept:

EARSeL is a scientific network of European remote sensing institutes, coming from both academia and the commercial/industrial sector. EARSeL is unique in that, it represents the interests of these institutes rather than individuals, although individual membership is possible. Currently, there are about 250 member laboratories (see EARSeL Directory of Members). It was founded in 1977 under the auspices of the European Space Agency, the Council of Europe and the European Commission, and registered on 13 December 1977 under French law by the Tribunal d'Instance in Strasbourg, France. EARSeL is run by a Council of elected national representatives from each country where there are member laboratories and an executive Bureau, elected by the Council.

See more: http://earsel.org/

Related Papers:

1. Exploring the Importance of Monitoring the Fire Risk Index in the vicinity of Cultural Heritage Sites in Cyprus using Sentinel Remote Sensing data, Kouhartsiouk D.,

Agapiou A., Lysandrou V., Themistocleous K., Nisantzi A., Hadjimitsis D. G., Lasaponara R., Masini N., Krauss T., Cerra D., Gessner U., 11th EARSeL Workshop, 25-27 September 2017 Chania, Crete.

3.14 EUROMED, 1-3 December 2017, Thessalian, Greece

2° Πανελλήνιο Συνέδριο
Ψηφιοποίησης Πολιτιστικής
Κληρονομιάς - 2017

Key concept:

The 2nd Conference on the Digitization of Cultural Heritage 2017, is the result of a long collaboration between University Bodies, State and Civil Society Organizations, Greece and Cyprus for many years, is combined with the EuroMed Global Conferences organized by CUT (Cyprus University of Technology) every two years. The ambition of the conference is to meet and interact with scientists and professionals working in culture, education, research, digital technologies and tourism, sectors that are cutting edge issues for Greece and Europe at the current juncture. The role of the research into the cultural heritage in the modern world of disseminating information is extremely important.

Related Papers:

1. Benefits derived from “ATHENA” Horizon 2020 Twinning project in the field of Remote Sensing for Cultural Heritage, Hadjimitsis D.G., Agapiou A., Lyssandrou V., Nisantzi A., Christofe A., Tzouvaras M., Papoutsa C., Mamouri R., Mettas C., Evagorou E., Themistocleous K.,. EUROMED 2017, pp 727-731.

3.15 CAA, 19-23 March 2018, Tubingen, Germany

Key concept:

The Computer Applications and Quantitative Methods in Archaeology (CAA) Annual Conference is one of the major events in the calendar for scholars, specialists and experts in the field of computing technologies applied to archaeology.

The 46th Computer Applications and Quantitative Methods in Archaeology Conference (CAA 2018) has been given the theme "Human history and digital future". The conference will address a multitude of topics. Through diverse case studies from all over the world, the conference will show new technical approaches and best practice from various archaeological and computer-science disciplines. The conference will bring together hundreds of participants from around the world in parallel sessions, workshops, tutorials and roundtables.

Related Papers:

1. Earth observation technologies and cultural heritage needs through the ATHENA TWINNING PROJECT", Hadjimitsis D. G., Agapiou A., Lysandrou V., Nisantzi A., Christofe A., Tzouvaras M., Papoutsa C., Mamouri R., Mettas C., Evagorou E., Themistocleous K., Lasaponara R., Masini N., Danese M., Sileo M., Krauss T., Cerra D., Gessner U., Schreier G., CAA 2018, 19-23 March 2018, Tubingen, Germany.

ANNEX I

Oral Presentations

1. Capitalize on the Experience of the ATHENA Project for Cultural Heritage for the Eratosthenes Centre of Excellence for the Benefit of the East Med Region, Hadjimitsis D. G., Themistocleous K., Evagorou E., Michaelides S., Christofe A., Nisantzi A., Neocleoys K., Papoutsa C., Mettas C., Tzouvaras M., Loulli E., Kouta G., Danezis C., Lasaponara R., Masini N., Cerra D., Schreier G. and Papadavis G., 7th International Conference, EuroMed 2018, Nicosia, Cyprus, October 29–November 3 - In book: Digital Heritage. Progress in Cultural Heritage: Documentation, Preservation, and Protection - DOI: 10.1007/978-3-030-01762-0_56.
2. Remote sensing archaeology knowledge transfer: examples from the ATHENA twinning project, Hadjimitsis D. G., Agapiou A., Lysandrou V., Nisantzi A., Christofe A., Tzouvaras M., Papoutsa C., Mamouri R.E., Mettas C., Evagorou E., Themistocleous K., Papageorgiou N., Lasaponara R., Masini N., Biscione M., Danese M., Sileo M., Krauss T., Cerra Gessner U., Schreier G. and Michaelides S., Remote Sensing Technologies and Applications in Urban Environments - SPIE Remote Sensing 2018, Berlin, Germany - DOI: 10.1117/12.2325532.
3. Monitoring cultural heritage sites affected by geohazards, Themistocleous K and C. Danezis, Earth Resources and Environmental Remote Sensing/GIS Applications - SPIE Remote Sensing 2018, Berlin, Germany - DOI: 10.1117/12.2325455.
4. Digitization issues in documenting cultural heritage with drones: case study of Foinikas, Cyprus - Conference: Earth Resources and Environmental Remote Sensing/GIS Applications - SPIE Remote Sensing 2018, Berlin, Germany - DOI: 10.1117/12.2325459
5. The innovative documentation of cultural heritage using H-BIM: case study of Asinou church, Themistocleous K., Earth Resources and Environmental Remote Sensing/GIS Applications - SPIE Remote Sensing 2018, Berlin, Germany - DOI: 10.1117/12.2325453
6. Study of ancient monuments' seismic performance based on Passive and Remote Techniques, Kyriakides N., Illampas R., Lysandrou V., Agapiou A., Masini N., Sileo M., Catapano I., Gennarelli G., Lasaponara R., Soldovieri F., Hadjimitsis D. G., 16th European Conference on Earthquake Engineering (16ECEE), 18-21, June, 2018, Thessaloniki, Greece.

7. From space to ground. Digital techniques or the investigation of monuments and sites, 10th MONUBASIN “Natural and Anthropogenic Hazards and Sustainable Preservation”, Lysandrou V., Agapiou A., Kyriakides N., Hadjimitsis D. G., , 20-22 September 2017, Athens, Greece.
8. Benefits derived from “ATHENA” Horizon 2020 Twinning project in the field of Remote Sensing for Cultural Heritage, Hadjimitsis D.G., Agapiou A., Lyssandrou V., Nisantzi A., Christofe A., Tzouvaras M., Papoutsa C., Mamouri R., Mettas C., Evagorou E., Themistocleous K.,. EUROMED 2017, pp 727-731.
9. ATHENA: Center of Excellence in Cyprus in the Field of Remote Sensing for Cultural Heritage in the Areas of Archaeology and Cultural Heritage, Hadjimitsis D. G., Agapiou A., Lysandrou V., Branka C., Themistocleous K., Nisantzi A., Lasaponara R., Masini N., Krauss T., Cerra D., Gessner U., Schreier G., 6th GEOBIA 2016, 14-16 September 2016 / Enschede, The Netherlands.
10. Satellite based investigation for detection of ancient tombs’ looting in Cyprus, Agapiou A., Lysandrou V., 2nd Computer Applications and Quantitative Methods in Archaeology (CAA GR) 2016, Athens, Greece 20-21 December 2016.
11. Observing the changes in landscape around the historical capital of Nicosia using multi-spectral multi-temporal datasets Cuca B., Agapiou A., Hadjimitsis D.G., 6th International Euro-Mediterranean Conference (EuroMed 2016), 31 Oct. – 05 November 2016, Nicosia, Cyprus.
12. Searching data for supporting archaeolandscapes in Cyprus: an overview of aerial, satellite and cartographic datasets of the island, Agapiou A., V. Lysandrou, K. Themistocleous, B. Cuca, R. Lasaponara, N. Masini, T. Krauss, D. Cerra, U. Gessner, G. Schreier, D. Hadjimitsis, Fourth International Conference on Remote Sensing and Geoinformation of the Environment (RSCy2016), 4-8 April, 2016, Cyprus.
13. Automatic damage detection for sensitive cultural heritage sites, Cerra D., Tian J., Lysandrou V., Plank S., XXIII ISPRS Congress 2016, 12-19 July, 2016, Prague.

Capitalize on the Experience of the ATHENA Project for Cultural Heritage for the Eratosthenes Centre of Excellence for the Benefit of the East Med Region

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Abstract. The "ATHENA" H2020 Twinning project seeks to establish a Center of Excellence in the field of Remote Sensing for Cultural Heritage through the development of an enhanced knowledge base and innovative methods in the areas of Archaeology and Cultural Heritage. This paper presents an overview of the ATHENA twinning project as well a review of the remote sensing in archaeology. The ATHENA stakeholder hub is presented through a WEBGIS platform. The importance of capitalizing on the experience of running the ATHENA project for the benefit of the ERATOSTHENES Centre of Excellence (ECoE) is explained. In recent years, Earth Observation (EO) techniques have been used extensively for archaeological and cultural heritage applications, which makes the ECoE a key player in EO activities in the Eastern Mediterranean region. The different areas that are under the umbrella of the remote sensing in archaeology sector are categorized based on the review findings. Finally, how Earth observation and remote sensing is spread out through research activities in the Eastern Mediterranean region from 1998 to 2018 is presented based on the Scopus engine.

Keywords: Remote sensing · Copernicus · Athena centre for cultural heritage Excelsior · ECoE

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https://doi.org/10.1007/978-3-030-01762-0_56

1 What Is 'ATHENA'

The "ATHENA" H2020 Twinning project seeks to establish a Center of Excellence (CoE) in the field of Remote Sensing for Cultural Heritage through the development of an enhanced knowledge base, capacity building and innovative methods in the areas of Archaeology and Cultural Heritage (CH). The ATHENA center has been established by twinning the existing Remote Sensing and Geo-environment Research Laboratory/Eratosthenes Research Centre-ERC. at the Cyprus University of Technology (CUT) with counterparts from other Member States of the EU, such as the Institute of Archaeological and Architectural Heritage of the National Research Council of Italy (IBAM-CNR) and the German Aerospace Centre (DLR). The close collaboration between the ATHENA CoE and other experts in the field of Remote Sensing for Cultural Heritage in the EU will form a synergic network that will enhance knowledge transfer and improve capacity building of the existing ERC staff.

The ATHENA project is expected to have direct and indirect social, scientific and economic impacts, through the creation of new jobs, increased research activity and knowledge transfer. The implementation of the project will facilitate future collaborations with experts of the Archaeology and CH sector at a European level, increase the CoE's research capabilities and enhance the research and academic profile of all participants. The location of the ATHENA CoE in Cyprus is especially important, as the region has been inhabited for thousands of years before and there is a wealth of tangible and intangible archaeological and CH remains.

During times of economic instability, national considerations overrule the process of European integration. CH is an integral element of a European set of values and respect for heritage is vital for developing a common European identity. Recently, the CH sector has undergone a number of challenges as a result of the financial crisis that hit Europe, including the decrease of public budgets, urbanization, globalization and technological changes, among others. Within this context, CH professionals are seeking to improve currently used methodologies in order to better understand, protect and valorize the common European past and common identity.

ATHENA seeks to improve and expand collaboration between low performing and leading institutions to use remote sensing technologies to support the CH sector. The ATHENA project was developed based on EU policies and international conventions related to Cultural Heritage protection, management and best practice, including the Europa Nostra policy documents; COM (2014) 477; UNESCO and EU conventions and multilateral treaties related to the protection of CH).

2 Remote Sensing in Archaeology and Cultural Heritage

EO techniques have become an indispensable tool for CH and archaeological investigation. Within the past 20 years, EO techniques have been used for the detection of cultural remains to the documentation, monitoring and preservation as found in the last 20 years. EO techniques are a non-invasive and cost-effective method for accessing data from a large area, especially in the case of archaeolandscapes. Such techniques enable CH experts to gain extremely precise results, thereby facilitating the different phases of heritage management, including survey, mapping, excavation, documentation, monitoring at diverse scales of interest, moving from small artifacts to architectural structures and landscape reconstruction and vizualization. Aerial and satellite data, in-situ data from ground sensors, databases such Geographic Information Systems (GIS) as well as augmented and virtual reality have revolutionized the archaeological and CH sector. For example, it is now possible to integrate satellite and ground archaeological and CH data to reconstruct an ancient environment, including the mapping of past flora and fauna and anthropological aspects.

There are dramatic differences in the cost and capabilities of different EO equipment. The increasing availability of free data and open access software tools can be used with in situ investigations and computer-based analysis, thereby providing new opportunities for the operational exploitation of archaeological results. The impact of EO technologies for archaeology experts [1] as well as end-users, which are currently underexploited, are expected to have a larger diffusion in the cultural heritage access and exploitation in the future, especially in the touristic sector. It is important to highlight the following areas are classified as the most important sectors of the wider area of remote sensing in archaeology research arena: (a) *airborne photography*: UAV [2, 3] and LIDAR [4]; (b) *passive satellite remote sensing* [5]; (c) *active satellite remote sensing*; (d) *ground remote sensing* that includes geophysical survey [6], magnetometry [7] and field spectroscopy [5].

Over the past two decades, the use of space technologies in archaeology and CH has increased for several reasons, including the improved spectral and spatial resolution of satellite sensors, the availability of user-friendly software and the recent trend for archaeologists to study the dynamics of human frequentation in relation to environmental changes. Indeed, EO techniques are very beneficial for archaeological and CH investigations, due to their reduced costs, time and risk associated with excavations and the creation of site strategies that focuses on conservation and preservation. In addition, the multispectral capability of satellite images can also be used to the identify the differences in texture, moisture content, roughness, topography, various types of terrain, vegetation cover, lithological and geological composition and other information used in archaeological studies. For example, crop-marks can be detected by spectral variations in specific channels more sensitive to vegetation (as near infrared) (see Fig. 1) or spectral indices (i.e. mathematical combinations of different spectral channels) as NDVI, SAVI, VI etc. by using multi-spectral images. The thirteen (13) spectral bands (443–2190 nm) and HR imaging capabilities in visible and near-infrared bands at 10 m spatial resolution have been already tested for archaeological prospection and monitoring [8–10].

In addition, local changes in the drainage capability of the soil, which are referred to as damp-marks, can be identified by spectral variations in specific channels more sensitive to moisture or spectral indices (see Fig. 2) as NDVI or difference in moisture in satellite SAR data [2] as in the case of Cosmo Skymed (see Fig. 2) acquired for the archaeological area of Metapontum. As well, shadow marks, which are micro/medium-micro-topographic relief linked to archaeological remains, as artworks, platforms, ditches and shallow remain, can be revealed by changes in colour or texture due to the presence of shadow through the use of spectral data.

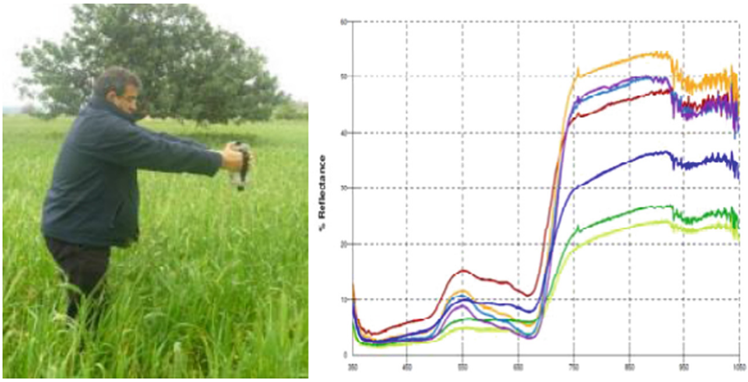

Fig. 1. Field spectroscopy in archaeological sites with typical spectral signatures of buried archaeological crops.

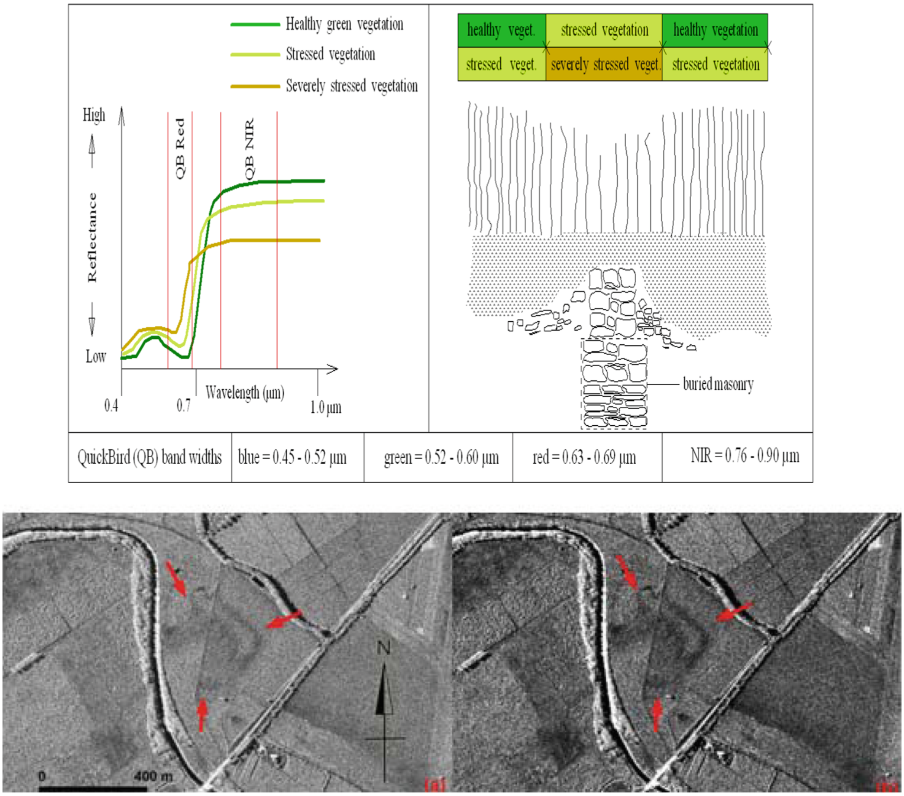

Fig. 2. Up-spectral response by QuickBird imagery of archaeological crop marks-Bottom-Cosmoskymed view of palaeochannels (Damp-marks) in Metapontum archaeological area (additional detail in [2]).

The European Commission Copernicus programme provides new opportunities in the EO sector and supports cultural heritage and cultural heritage monitoring [7]. Indeed, the Copernicus programme uses EO data and services for archaeological remote sensing [7] as highlighted during the Copernicus for Cultural Heritage Workshop (http://workshop.copernicus.eu/cultural-heritage).

The authors provide the following findings regarding a review of research activities using RS and EO techniques in cultural heritage and archaeology, focusing on the east-med region using the Scopus engine as shown in Fig. 3, from 1998 to 2018 [13]. It is important to highlight based on the Scopus results, the active participation of the ERC group in EO, also helped the pillar of cultural heritage which will be one of the pillars of the ECoE.

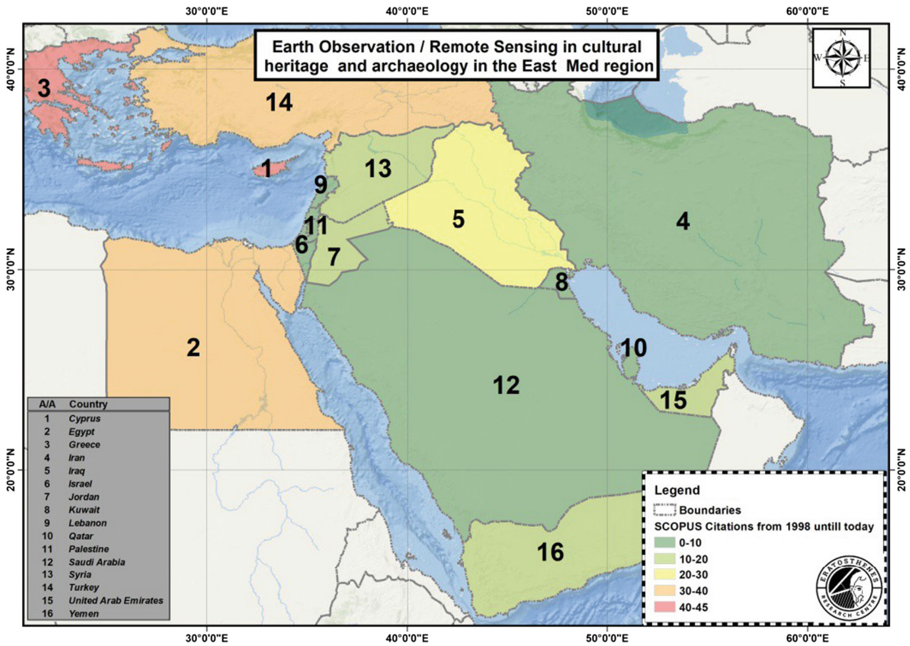

Fig. 3. Research activity in the East-MED region from 1998–2018 using Scopus engine (citations).

3 ATHENA Database: Stakeholder Hub

A relational database has been created to manage the information about the network of Institutions (laboratories, research groups) involved in Remote Sensing and Cultural Heritage. Additionally, information on Projects (including scientific expeditions and scientific missions) focused on EO tools was considered. The current database contains data information concerning **143 institutions** of different states and **14 projects** along with predefined queries to facilitate the search and use of the database (see Fig. 4). Specific queries can be created for specific needs and requests. The information currently offered by the database is a fundamental starting point for the creation of networks and collaborations. It has been conceived as an open updatable tool that will be continuously enriched during and after the project by both project partners and crowd-sourcing. Therefore, a specific web interface will be defined and set in order to enable the updating of the data base, promoting the growth of the network, facilitate contacts and collaborations.

Fig. 4. WebGIS Map of the existing database: hub for collaboration.

By merging together the existing ERC hub of over 450 stakeholders that has expanded since 2007 during the EO activities with the ‘ATHENA’ Hub shown above, it is apparent that the region can be benefit of this available platform for future collaborations and future activities for solving societal problems.

4 How to Capitalize on the Experience of the ATHENA

One of the main aims of the ‘ATHENA’ Twinning project [11] after its completion at the end of 2018 is to secure the sustainability of the Centre. This is very challenging since the only source of funding will be competitive funding and services. Indeed, the ATHENA will be one of the pillars of the Eratosthenes Centre of Excellence (ECoE) which will upgraded through the EXCELSIOR H2020 Teaming project (www.excelsior2020.eu) as shown in Fig. 5. The aim of the EXCELSIOR teaming project is to upgrade the existing ERATOSTHENES Research Centre (ERC), established within the Cyprus University of Technology (CUT) into a sustainable, viable and autonomous Centre of Excellence (CoE) for Earth Surveillance and Space-Based Monitoring of the Environment, which will provide the highest quality of related services on the National, European and International levels [12]. The ERATOSTHENES CoE (ECoE), with its extensive expertise and infrastructure, can be a hub for the Earth observation activities in the eastern Mediterranean area due to the key geostrategic position of Cyprus.

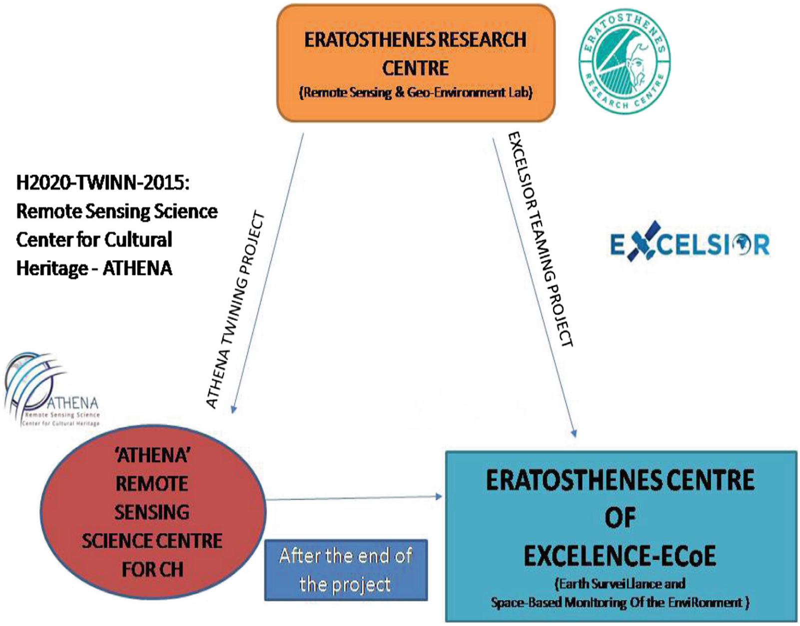

Fig. 5. How to secure sustainability of the 'ATHENA'? Capitalize on the Athena experience at the Eratosthenes Centre of Excellence (www.excelsior2020.eu).

The ERC is already an existing stakeholder hub with over 400 stakeholders from Europe, USA, Asia, Africa. Through ATHENA, this hub has already expanded the potential of the Earth observation area especially in the East Meditteranean Middle East North Africa (EMMENA) region. This hub will benefit society, academia, government and industry. Through the ECoE, EO services in the natural and built environment will be offered including also the cultural heritage. The ERC is a Copernicus Academy member and this assisted the sustainability of the ATHENA cultural heritage pillar within the ECoE. The ERC has already secured some funds through the ATHENA twinning and EXCELSIOR teaming benefits. The knowledge transfer from the twining partners of ATHENA, CNR and DLR to the CUT team (ERC) in the areas of SAR, geophysical surveys has been a great benefit of the ERC.

The ERC is a member of the Copernicus Academy network and has already promoted 'ATHENA' and 'EXCELSIOR' through several stakeholders' meetings, events and workshops. Such activities have already contributed to the Network's goals for providing researchers, scientists and entrepreneurs with the skills required for accessing Copernicus data and information services through a series of trainings and the development of relevant educational material. The Copernicus Academy also works to increase the exchange of ideas and best practices across borders and disciplines while contributing to the development of the use of EO data in general and Copernicus data and information in particular, in various public or private user organizations or industries. through ERC activities by presenting ATHENA and EXCELSIOR, new EO practices in teaching, tools and interactive workshops have been developed.

One of the significant impacts of running the **'ATHENA'** project under the umbrella of the ERC 'a pure multi-disciplinary Earth observation group' which have already been capitalized are the following: (a) merging ATHENA and ERC existing stakeholders hubs: this will be an open hub platform for the *regional* and *European* use (b) increase visibility of our group (c) applying EO techniques more efficiently for natural and built environment including cultural heritage (c) social media/networking: promotion of community engagement, fostering an 'open science' environment through the use of digital and social media (d) the use of the EO for the implementation of the *UN Sustainable Development Goals* through the application of satellite remote sensing for real practical problems (d) active participation of local stakeholders (e) securing more funds in the wider area of risk management and environment (natural and built). The implementation of a novel strategic infrastructure unit to monitor natural hazards in Cyprus and eastern-med region through a new funded project named CyCLOPS will help boost the ECoE and the region for monitor, catalogue and understand the natural hazards for any intended application including natural and built environment (e.g., heritage).

5 Conclusions

This manuscript provided a review of the different available methods and categorized within the umbrella of the remote sensing in archaeology. Through 'ATHENA' the existing ERC stakeholder hub has increased and improved for the benefit of the local and the region. One of the aims of the ATHENA Twinning project was to sustain the existing cultural heritage sector within the ERC. Indeed, such goals have been achieved and will be further boosted through the 'EXCELSIOR' H2020 Teaming project in which the existing ERC will be upgraded to a Centre of Excellence-ECoE.

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Remote sensing Archaeology knowledge transfer: examples from the ATHENA Twinning project

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ABSTRACT

ATHENA is an on-going Horizon 2020 Twinning project aiming to promote remote sensing technologies for cultural heritage (CH) applications in Cyprus. ATHENA project brings together the Eratosthenes Research Center (ERC) of the Cyprus University of Technology (CUT) with two internationally leading institutions of Europe, namely the National Research Council of Italy (CNR) and the German Aerospace Centre (DLR). The project's scope is to position the ERC regionally and stimulate future cooperation through placements at partner institutions and enhance the research and academic profile of all participants. The scientific strengthening and networking achieved through the ATHENA project could be of great benefit not only for Cyprus but for the entire Eastern Mediterranean, bearing a plethora of archaeological sites and monuments urgently calling for monitoring and safeguarding.

The preservation of CH and landscape comprises a strategic priority not only to guarantee cultural treasures and evidence of the human past to future generations, but also to exploit them as a strategic and valuable economic asset. The objective of this paper is to present knowledge transfer examples achieved from the ATHENA project through intense training activities. These activities were also designed to enhance the scientific profile of the research staff and to accelerate the development of research capabilities of the ERC. At the same time the results from the training activities were also exploited to promote earth observation knowledge and best practices intended for CH. The activities included active and passive remote sensing data used for archaeological applications, Synthetic Aperture Radar (SAR) image analysis for change and deformation detection, monitoring of risk factors related to cultural heritage sites including archaeological looting etc.

Keywords: ATHENA, Archaeology, training activities, Twinning project, Space technologies

INTRODUCTION

In the last decade earth observation and remote sensing has been widely used to support archaeological research and cultural heritage management. This is well documented in the numerous publications of the last years and from bibliometric statistics [1, 2]. In addition to this, joint research projects are funded so as to promote sustainability and best practices against natural and anthropogenic hazards [3,4]. The potential use of earth observation and remote sensing has been also recognized by UNESCO who has supported the creation of the first International Centre on Space Technologies for Natural and Cultural Heritage (HIST) [5]. It was officially inaugurated in 2011 under the auspices of UNESCO and with support from its host, the Center for Earth Observation and Digital Earth (CEODE), Chinese Academy of Sciences (CAS) was aiming to "*build the capacity of UNESCO Member States to use space-based Earth*

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observation to monitor, document, model, and present natural and cultural heritage sites of national or international significance” [5].

While Europe is, along with USA and China, one of the leading members of the world, regarding the systematic exploitation of space earth observation and remote sensing technology, research activities are still fragmented within the continent. To this end, Horizon 2020 (H2020) -the biggest EU Research and Innovation programme ever with nearly €80 billion of funding available from 2014 to 2020- has dedicated for specific Coordination and Support Action (CSA) calls so as to enhance networking activities between the research institutions of low performance in research countries and internationally-leading counterparts at EU level.

The 3-year duration H2020 ATHENA proposal submitted under this call (i.e. Widespread Twinning 2015) was eventually approved by the European Commission with a total budget of approximately €1 million, and it is currently running for the period Dec. 2015 until Nov. 2018. The ATHENA project [6] is aiming to enhance the capacity of the Archaeology and Cultural Heritage Section [7], of the Remote Sensing and Geo-Environment Laboratory, part of the Eratosthenes Research Center [8], by bringing together researchers of the group with leading experts in the field from the National Research Council of Italy (CNR) [9] and the German Aerospace Centre (DLR) [10].

The National Research Council of Italy (CNR) has a strong record in the exploitation of remote sensing technologies for cultural heritage in various parts of the world, with also scientific missions in Southern America and China, while the German Aerospace Centre (DLR) is a leading institute in the domain of space technologies. Following an internal SWOT analysis of the group and based on the research agenda of the leading institutions, a detailed knowledge transfer program has been set up for the whole duration of the ATHENA project. This is outlined in the following sections along with some of the results.

KNOWLEDGE TRANSFER

Research Topics

The ATHENA project focuses on the knowledge related to cultural heritage implementing actions based on multidisciplinary collaborations and closes the gap between cross-disciplinary research and methods through different scientific domains. It is expected that the ATHENA project directly and indirectly benefits the project consortium as well as associated stakeholders. The combination of innovative methodologies to enhance the understanding of European cultural heritage by means of remote sensing techniques brought new knowledge, collaboration across disciplines, and social benefits. The innovative procedures and applications enabled remote communication and collaboration across the industry, professionals, experts, researchers and academia.

The main research topics of the ATHENA project that were set up for training and further studding included the following:

- Use of remote sensing (RS) techniques for the detection of buried antiquities and archaeological residues.
- Use of RS techniques and environmental information systems for supporting, understanding, analyzing, documenting and monitoring the archaeological landscape, systematic and rescue archaeological excavations, as well as isolate monuments and their related environment.
- Documentation and structural analysis of standing remains of CH; monitoring of known sites regarding their vulnerability and exposure to natural and anthropogenic hazards.
- RS for estimation of risk factors related to CH sites, such as natural (landslides, flooding, sea level rise) and man-made (i.e. impact of urban and modern infrastructures, land use, looting, deliberate destruction thru war and conflict).
- Experimental RS applications for archaeological investigations.

The above research activities were envisaged through various close-range remote sensing techniques such as ground penetrating radar, and middle range (UAV’s), distant from low Earth orbit (satellite imagery in SAR, optical and hyperspectral domain), desk-base (GIS, FEM, etc.) and their integration with archaeological and cultural context.

Research approach

The methodological approach of the ATHENA project is based upon the support activities carried out from the internationally leading research institutions. These integrated activities thereby contribute to the overall programme and scientific objectives of the project. The approach of the project is described below:

- Detailed literature reviews provide the necessary background knowledge and assist current staff of the low performing country in formulating well-defined background and target its tasks.
- Evaluation of existing gaps of the CUT's lab both in terms of knowledge, capacity, equipment etc.
- Training of the CUT researchers from all leading research institutions in two main thematic areas: Remote sensing in Archaeology (by CNR) and new remote sensing technologies and tools and Environmental Information Systems (by DLR), including various subthemes, such as: interferometry/radar, hyperspectral processing, multi-temporal RS analysis, satellite monitoring for archaeological looting, Copernicus contribution to CH.
- Short term visits of researchers from Cyprus to the project partner organizations DLR and CNR and vice versa.
- Synthesis and integration of different remote sensing techniques for supporting archaeological research and cultural heritage management and monitoring.
- Joint workshops and summer schools with all project partners, joint interpretation, presentation and archiving of the data from the various activities carried out during the collaboration.

KNOWLEDGE TRANFER EXAMPLES

Research activities

Among the first examples of the research between the CUT and CNR teams was the application and evaluation of optical satellite images for the detection of buried relics nearby the modern village of Lucera, in the Tavoliere territory (Apulia region) in Southern Italy. In this area, a large number of crop marks that reveal traces of long human habitation since the Neolithic age have been identified, while the "extraordinary interest in studying crop marks in this area is explained by the presence of a great morphological variety of traces ranging from curvilinear to linear and quadrangular shapes, linked to the different historical phases of human presence at the site" [11].

The experiments were contacted using both GeoEye and Quickbird images, by applying various image enhancement techniques such as the Normalized Difference Vegetation Index (NDVI), Simple Ratio Index (SR) as well as to evaluate the performance of the orthogonal equations [12, 13]. The results have shown "the potential use of the linear equations and in particular, the use of ratios between the different components can improve the detection of crop marks even more. The best discriminability of the Neolithic crop marks is obtained by the vegetation/crop and vegetation/soil ratios. In addition these ratios were able to improve the quality of the images in shadow areas [11]. Some results from this application are shown in Figure 1.

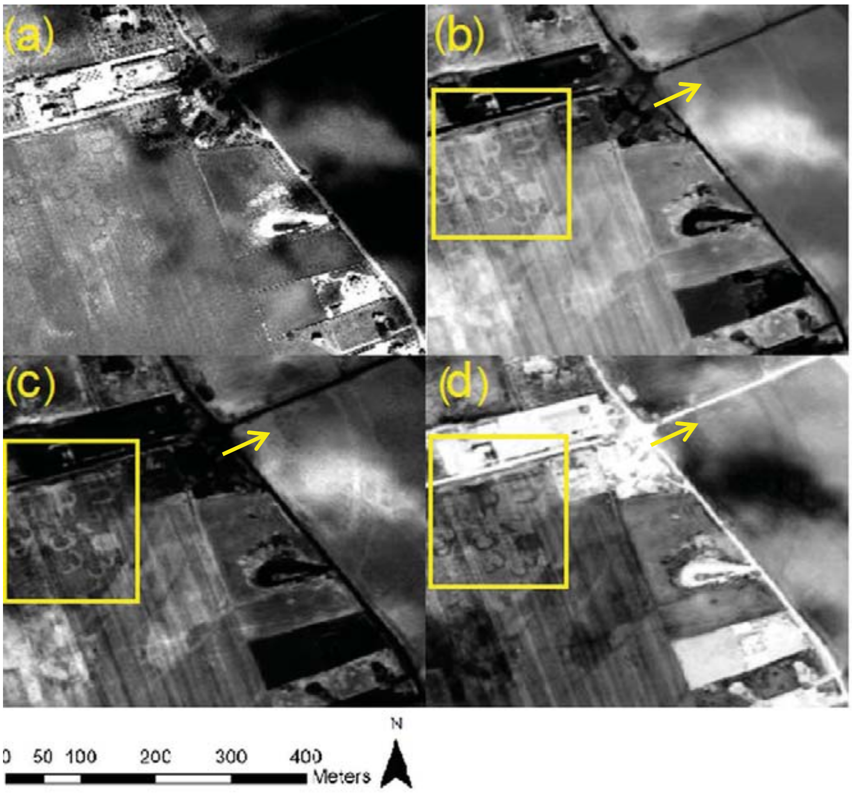


Figure 1. Palmori archaeological site (41.545551°N and 15.436549°E, WGS 84). (a) Panchromatic band; (b) vegetation coefficient; (c) NIR/red ratio; and (d) vegetation/crop ratio applied in the 2012 GeoEye image. The vegetation coefficient and the NIR/red and vegetation/crop mark ratios are able to reduce the shadow caused by the clouds. The yellow arrows indicate part of a curvilinear mark, referable to a ditch bordering Palmori settlement. The visual comparison of Figure 5a,b shows that the features evident from the 2012 scene are not visible in the 2007 picture and vice versa. Figure from [11].

In parallel with the above research, the research group was working with the DLR researchers in order to asses several hyperspectral indicators for the detection of buried archaeological relics. While the application of several vegetation indices and other image features has been widely used in the past in order to enhance the interpretation of satellite images, it has not been tested for their performance. To this end, the research was oriented to "the evaluation of the statistical dependence between the extracted features and a digital map indicating the presence of buried structures using information theoretical notions. Based on the obtained scores on known targets, the features can be ranked and the most suitable can be chosen to aid in the discovery of previously undetected crop marks in the area under similar conditions" [14]. Three case studies were reported in this analysis: the Roman buried remains of Carnuntum (Austria), the underground structures of Selinunte in the South of Italy, and the buried street relics of Pherai (Velestino) in central Greece. This semi-automatic ranking of the indices—for each specific case study—according to their 'archaeological' informational content may help experts in focusing on other areas in close proximities, based on the most meaningful indices for further investigation activities. Such researches are usually carried out via visual analysis, and the pre-selection of the most suitable spectral features could maximize the success rate of the interpretation of crop marks. An example of the ranking of several vegetation indices based on their "archaeological information" for the case study of Selinunte in Italy is given below:


1 - TCARI, 100%

2 - NDMI, 98.3%

3 - MCARI, 93.5%

4 - TVI, 90.9%

5 - MTVI, 90.9%

6 - MCARI2, 89.6%

7 - MRENDVI, 88.2%

8 - ARVI, 85.6%

9 - EVI, 84.3%

10 - VARI, 83.9%

11 - TrVI, 83.3%

12 - PSRI, 82.7%

13 - RENDVI, 82.5%

14 - GARI, 81.7%

15 - IPVI, 81.7%

16 - NDVI, 81.6%

17 - SAVI, 81.3%

18 - RDVI, 77.0%

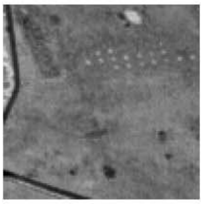
19 - GEMI, 77.0%

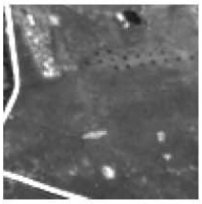
20 - DVI, 75.9%

21 - CRI1, 74.7%

22 - SR, 69.2%

23 - IronOxide, 67.5%

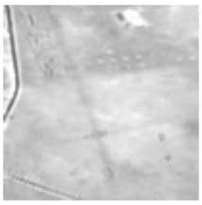
24 - GNDVI, 66.1%

25 - PRI, 64.5%

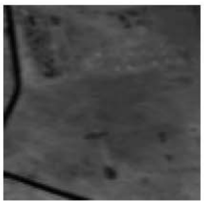
26 - GRVI, 59.0%

27 - SGI, 56.3%

28 - NDSI, 54.5%

29 - CRI2, 52.8%

30 - ARI2, 50.9%

31 - ARI1, 48.9%

32 - GDVI, 44.5%

33 - NLI, 42.0%

34 - BAI, 36.7%

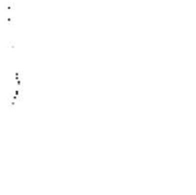
35 - VRE1, 35.0%

36 - SIPI, 0.0%

Figure 2. Detail of spectral indices computed for the Selinunte dataset. The indices are sorted from best to worst, according to the mutual information with the main crossroad in the area. A score is derived as the relative mutual information with respect to the one computed for the best index. The buried structures become less evident as the mutual information decreases. Figure from [14].

The main result of this research was showing that spectral indices, whose efficiency at discriminating crop marks depends on the case of study and the geographical area, can be ranked on a known study site and successfully transferred to a nearby site under investigation, under the assumption that variation in vegetation and soil characteristics are limited in a restricted area. This helps researchers in selecting the most suitable spectral indices at hand among hundreds of possibilities to carry out a meaningful analysis.

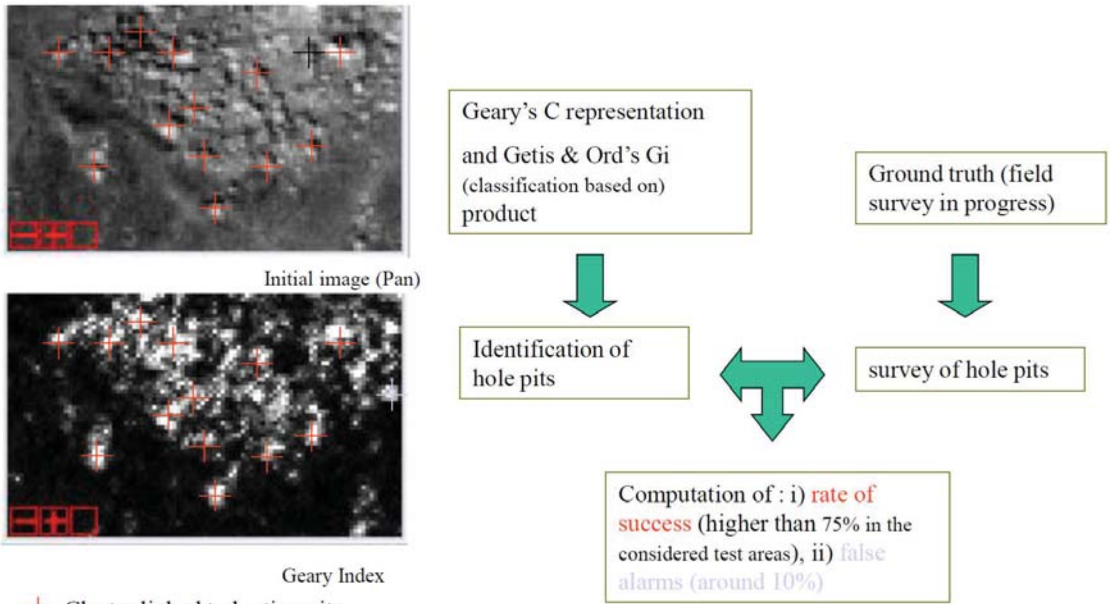
Training activities

An example of training activities and hands-on experience was the "Archaeological looting: Ancient problems and New approaches based on Remote Sensing" training event carried out in CUT premises. The preservation of cultural heritage and landscape is today a strategic priority, not only to preseve cultural treasures and evidence of the human past for future generations, but also to exploit them as a strategic and valuable economic asset, if inspired by sustainable development strategies. This is an extremely important key factor for countries which are owners of an extraordinary cultural legacy, which is particularly fragile due to its specific characteristics and risks at which CH is continuously exposed. Taking advantage of large-spatial coverage and a detailed spectral information, satellite remote sensing can be usefully adopted for contrasting looting, especially in countries located in South America or the Middle East, where the surveillance on site is not particularly effective and time consuming, or non practicable due to military or political restrictions [15].

The training activities organized by CNR were focused on the characterization of the looting phenomenon from a multi-faced prospective (as detailed below). In particular, the training activities were focused on the use of high spatial resolution satellite and aerial optical images and Lidar acquisition to quantitatively assess looting. An overview of methodologies and data processing for the identification and quantification of looting features (using both single date and multitemporal satellite images) were discussed for several study areas.

Moreover, advanced data processing based on both autocorrelation statistics and unsupervised classification have been presented, applied and discussed for significant study areas, as Dura Europos [16]; selected in Syria. The main topic were deeply focalized:

1. Looting as a complex problem
   - black market of looted items
   - social and anthropological view of looters;
2. Looting features from above: physical and spectral characteristics
   - Looting from optical satellite data
   - Looting from SAR satellite data
   - Looting from LIDAR
   - Looting from UAV optical image
3. An overview of Looting
   - Looting in diverse countries from Middle East to Peru, from Asia to Europe
   - Looting mapping and quantification
   - Visual inspection, Crowd sourcing and automatic data processing to map and quantify looting
4. Data processing from looting feature extraction
   - Classification to automatically detect looting in desert environment



+ Cluster linked to looting pits

+ False alarm

+ Looting pits not detected by means of local spatial autocorrelation

In Cahuachi, the detection of looting pits on mounds has been significantly improved by applying local spatial autocorrelation statistics.

Such improvement is still more evident if we compare the panchromatic satellite time series with the correspondent time series processed by local spatial autocorrelation statistics

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Monitoring cultural heritage sites affected by geohazards

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ABSTRACT

Currently, assessing geo-hazards in cultural heritage sites takes place after the geo-hazard has occurred. The long-term vulnerability of cultural heritage is commonly focused on the site itself, in response to environmental risks, without fully considering or understanding the entire geological and geotechnical context. However, the high costs of maintenance of cultural heritage sites directly enforce the prioritisation of the monitoring and conservation policies to ensure sustainable conservation. Monitoring the deformation of structures as well as their surroundings facilitates the early recognition of potential risks and enables effective conservation planning. This paper will present the results of the case study of the UNESCO World Heritage Site of Choirokoitia, Cyprus, where long-term low-impact monitoring systems such as UAVs and geodetic techniques were used to monitor and assess the risk from natural hazards on the archaeological site to evaluate potential geo-hazards.

Keywords: Cultural heritage, natural hazards, remote sensing, UAV, geodetic techniques

1. INTRODUCTION

Tangible cultural heritage includes various categories of monuments and sites, from cultural landscapes and sacred sites to archaeological complexes, individual architectural or artistic monuments and historic urban centres. Such places are continuously impacted and weathered continuously impacted by several environmental and anthropogenic factors, including climate change, precipitation, natural hazards, wars, etc [1-4]. However, there is limited data available regarding the effects of geo-hazards on cultural heritage sites [5]. Cultural heritage is vulnerable to geological disasters induced by earthquakes, volcanoes, floods and catastrophic landslides as well as other non-catastrophic slow-onset geohazards that can slowly affect the integrity and accessibility of the heritage, such as slow-moving landslides, sinkholes, ground settlement and active tectonics. Even if these phenomena can be responsible for large damages, they are largely neglected in the literature [6-8]. The long-term vulnerability of cultural heritage is commonly focused on the heritage itself (i.e., degradation and corrosion of building materials) in response to environmental risks [9-10], without fully considering or understanding the entire geological and geotechnical context. Currently, assessing geo-hazards in cultural heritage sites takes place after the geo-hazard has occurred. However, the high costs of maintenance of cultural heritage sites directly enforce the prioritisation of the monitoring and conservation policies to ensure sustainable conservation. Monitoring the deformation of structures as well as their surroundings facilitates the early recognition of potential risks and enables effective conservation planning [11].

On-site observation has been the most common way of monitoring cultural heritage sites and monuments in Europe. However, this procedure, that includes field surveying, ground-based data collection and periodical observations, can be time consuming and expensive, especially over large or remote areas is extremely difficult, expensive and time consuming [4]. Traditionally, deformation monitoring in cultural heritage sites is carried out by installing electrical sensors in selected structures with automatic systems for data acquisition and recording or by using portable instruments with manual reading of data taken at fixed time intervals [12-14]. However, such methods can only acquire data of the monitored structure within the cultural heritage sites, not the entire area of the site and its surrounding landscape [12]. Moreover, the installation of monitoring devices, such as optical targets, permanent GNSS stations or inclinometers, on the heritage sites and monuments can lead to aesthetic and functional impacts that can affect the integrity and availability of the heritage.
The case study of the UNESCO World Heritage Site of Choirokoitia in Cyprus is one of four case studies of the PROTHEGO project (www.prothego.eu). The focus of the PROTHEGO project is the development and validation of an

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innovative multi-scale methodology for detecting and monitoring European cultural heritage exposed to natural hazards, namely monuments and sites potentially unstable due to landslides, sinkholes, ground settlement, active tectonics as well as monument deformation, all of which could be affected by climate change and human interaction. PROTHEGO provides a new, low-cost methodological approach for the safe management of cultural heritage monuments and sites located in Europe, by integrating novel space technology based on radar interferometry (InSAR), long-term low-impact monitoring systems and indirect analysis of environmental contexts to retrieve information on ground stability and motion in the 400+ UNESCO's World Heritage List monuments and sites of Europe [3,4]. The development of the methodology for identifying cultural heritage sites affected by geo-hazards provided capacity building to the ATHENA Remote Sensing Science Center for Cultural Heritage at the Cyprus University of Technology (athena2020.eu/).

2. STUDY AREA

The field monitoring was conducted at the UNESCO World Heritage Site of Choirokoitia in Cyprus, which is one of the four demonstration sites of the PROTHEGO project. The Neolithic settlement of Choirokoitia, occupied from the 7th to the 4th millennium B.C., is one of the most important prehistoric sites in the eastern Mediterranean [15]. Included in the UNESCO World Cultural Heritage list since 1988, Choirokoitia is one of the best preserved settlements of this period in Cyprus and the Eastern Mediterranean. Located in the District of Larnaka, about 6 km from the southern coast of Cyprus, the Neolithic settlement of Choirokoitia lies on the slopes of a hill partly enclosed in a loop of the Maroni River. Occupied from the 7th to the 5th millennium B.C., the village covers an area of approximately 3 ha at its maximum extent and is one of the most important prehistoric sites in the eastern Mediterranean. It represents the Aceramic Neolithic of Cyprus at its peak, that is the success of the first human occupation of the island by farmers coming from the Near East mainland around the beginning of 9th millennium.

Figure 1. Left - Aerial view of Choirokoitia site, Center - Current condition of the site. Right - reconstruction of the houses

Excavations have shown that the settlement consisted of circular houses built from mud brick and stone with flat roofs and that it was protected by successive walls (figure 1). A complex architectural system providing access to the village has been uncovered on the top of the hill. The achievement of such an impressive construction, built according to a preconceived plan, expresses an important collective effort, with few known parallels in the Near East, and suggests a structured social organisation able to construct and maintain works of a large scale for the common good. A house consisted of several circular buildings equipped with hearths and basins arranged around a small courtyard where domestic activities took place. The houses belonged to the living, as well as to the dead who were buried in pits beneath the rammed earthen floors. Among the finds such as flint tools, bone tools, stone vessels, vegetal and animal remains, noteworthy are the anthropomorphic figurines in stone (one in clay), which point, together with funerary rituals, to the existence of elaborate beliefs. Since only part of the site has been excavated, it forms an exceptional archaeological reserve for future study. To date, 20 houses have been excavated which were constructed with limestone, clay and brick. The site depicts how people lived in the Neolithic era which was mostly through agriculture and raising domestic animals. According to UNESCO the site was officially abandoned in the 4th millenium BC. The reason for this still remains unknown [15].

3. LOCALE SCALE MONITORING

According to Margottini et al [16], the combined adoption of different survey techniques, such as 3D laser scanning and ground-based radar interferometry may be the best solution in the interdisciplinary field of cultural heritage preservation policies. Satellite radar interferometry is capable of monitoring surface deformation with high accuracy using precise

ground measurements. Once vulnerable sites are identified by InSAR satellite imagery, local-scale monitoring and advanced modeling can be used to monitor the cultural heritage sites over time. The locale scale monitoring methodology includes in-situ observation and remote sensing techniques, such as PS techniques, that are used to validate the impact of natural hazards. Topographic surveying using differential GNSS, Unmanned Aerial Vehical (UAV) images, photogrammetry and InSAR data are used to map slow ground movements, which are then compared and validated with ground based geotechnical monitoring in order to evaluate cultural heritage sites deformation trend and to understand its behaviour over time. As a result, areas exposed to potential risks and their evolution in time can be identified and crucial information can be provided to decision makers in order to protect cultural and heritage sites from natural hazards.
Locale scale monitoring provides the opportunity to detect and analyze deformation phenomena for monitoring and predicting geo-hazards using field survey techniques to measure and document the extent of damage of the natural hazard on the cultural heritage site. The geodetic techniques can be used in combination with UAVs for documentation purposes and 3D modeling comparison. The aerial imagery obtained from the UAVs can be imported into Structure in Motion software to create rapid and automated generation of a point cloud model and 3D mesh model in order to document and monitor the extent of geo-hazards at the cultural heritage site. The ground based geotechnical monitoring can then be compared and validated with InSAR data to evaluate cultural heritage sites deformation trends.

3.1 Methodology

During the PROTHEGO project (HERITAGE PLUS/0314/36- Joint Programming Initiative on Cultural Heritage and Global Change (JPICH) – HERITAGE PLUS), a methodology was developed to assess the risk from natural hazards on the archaeological sites and monuments from a geospatial perspective. This paper will evaluate the field monitoring techniques used to assess the geo-hazards in the study area of Choirokoitia, Cyprus. Local scale monitoring can be used to assess the severity of these geo-hazards by using integrated field monitoring techniques. Research indicates that the integration of InSAR data and conventional surveying offers the best solution for monitoring geo-hazards in cultural heritage sites [16-18]. Geotechnical techniques are used to measure deformation over a relatively short measurement base. In-situ measurements using UAV, total station, laser scanning and GPS are then used to further measure such movements. In order to document the cultural heritage site affected by geo-hazards, UAV images and laser scanning are used [19-20].

The research methodology focused on long-term low-impact monitoring systems as well as indirect analysis of environmental contexts to investigate changes and decay of structure, material and landscape [4, 21]. The methodology for the locale scale monitoring begins with using InSAR images to identify natural hazards in the UNESCO World Heritage demonstration sites. When the InSAR ground motion data indicate that a natural hazard took place at or near the demonstration site, field monitoring and verification is necessary to document and measure the extent of the change caused by the natural hazard, if any. Documentation of the damage can be performed either close range, using laser scanning or photogrammetry, or by low altitude sensors, using UAVs and drones. Measurements for calibration of these products are taken using GNSS and total station. After the change is identified using field verification, InSAR images are again used to verify and assess the extent of the damage to the cultural heritage site [22]. The methodology is presented in figure 2.

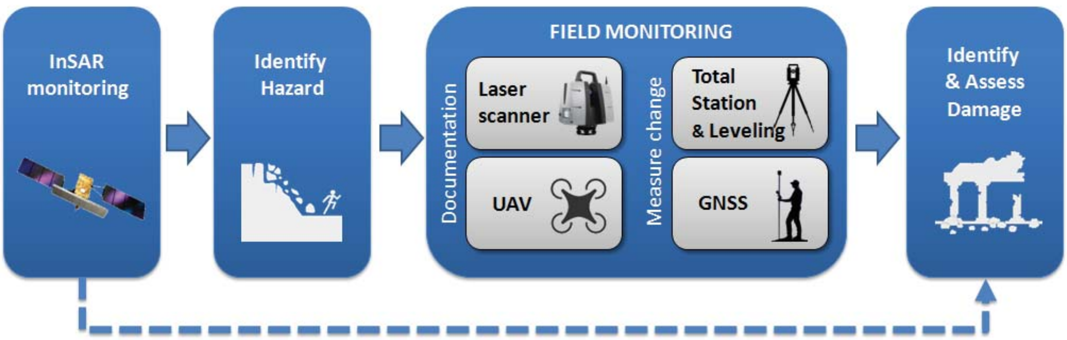

Figure 2. Methodology for local scale monitoring

3.2 Unmanned Aerial Vehicles (UAVs)

UAVs have become a common tool in cultural heritage and archaeological research as they provide higher resolution images compared with satellite imagery. Research indicates that unmanned aerial vehicles (UAVs) can be used for low-altitude imaging and remote sensing of geospatial information [23-26]. UAVs are being used for surveying cultural heritage sites due to their affordability, reliability and ease-of-use [23, 27-31]. UAV data provides more detailed surveys of the archaeological site [32-37], especially in areas that are inaccessible and/or dangerous which cannot be accessed directly using other systems or piloted aerial systems [38, 39]. Remote sensing technologies on a UAV platform are extremely useful for the detection and monitoring of cultural heritage features [24-26, 40]. UAVs can be a efficient, non-evasive and low cost resource to document cultural heritage sites 24-26, 40] and can be fitted with sensors which are able to produce an unprecedented volume of high-resolution, geo-tagged image-sets of cultural heritage sites from above [24, 25, 41-43]. UAVs provide an affordable, reliable and straightforward method of capturing cultural heritage sites, thereby providing a more efficient and sustainable approach to documentation of cultural heritage sites. Recent developments in photogrammetry technology provide a simple and cost-effective method of generating relatively accurate 3D models from 2D images [24, 27-29, 44]. To document cultural heritage site under threat from geo-hazards, UAV images can be used to create ortho-photos, dense clouds, 3D model and Digital Elevation Models [45]. The UAVs should be equipped with a 20mp camera to acquire images over the site with fixed ground control points for geo-referencing in order to produce a photogrammetric ortho-image and point cloud 3D model of the demonstration site and also for comparison over temporal intervals.

Figure 3: UAVs fitted with sensors

3.3 Laser Scanners

Laser scanners have become increasingly efficient in terms of point acquisition speed, portability, user friendly and cost [46]. Laser scan technology allows user to produces a high-precision digital reference data that records condition, provides a virtual model for replication, and makes possible easy mass distribution of digital data [32, 47] of the cultural heritage site. Site documentation can be conducted using a laser scanner to monitor the site so that comparison over temporal intervals will be performed. The laser scanner cloud point can be used for further 3D modelling of the area and to generate a Digital Surface Model (DSM) of the site.

3.4 Surveying techniques

For the local-scale monitoring, surveying techniques are used to determine the absolute positions and positional changes of any point on the surface and geotechnical techniques to measure deformation over a relatively short measurement base. Surveying techniques, such as total station, leveling, and Global Navigation Satellite Systems (GNSS), are used to measure the positional changes of any point on the surface at millimeter level accuracy. They have also been successfully used for measuring deformations in archaeological areas affected by hazards [46, 48, 49]. GNSS provides location coordinates in global geographical system, highly useful in combination with other techniques, being appropriate in documenting mass targets and structural deformation [50]. Electronic data collection with total station instruments permits the quick acquisition of large amounts of field data, together with the efficient and error-free transfer of the data to a computer [51].

3.5 Geodetic techniques

A local geodetic network is first established within the cultural heritage site (figure 4). The network consists of a reference point and additional nodes, established at specific points of interest (i.e. points on peaks or ridges that may indicate/warn of a potential hazard) [20, 22]. Network points are measured regularly using satellite (GNSS) and ground measurements (via high precision total stations and levels) to estimate the potential relative motion with respect to the network reference point, during the life-span of the monitoring activity. The number of points is a function of site vulnerability parameters as indicated by geology specialists. The network nodes (or control points) need to be incorporated into the site and placed in such way as to ensure mutual visibility with the total station setup at the reference point [20, 22].

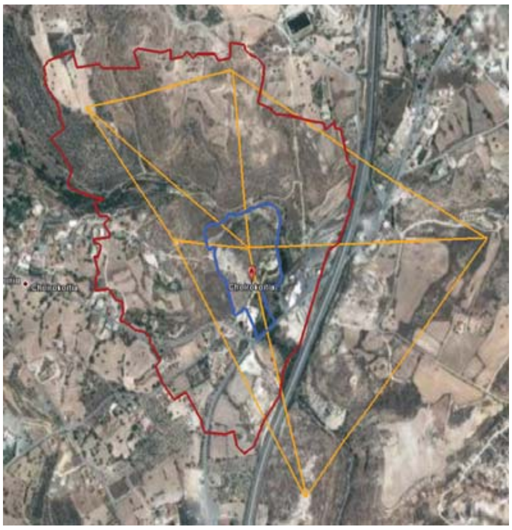

Figure 4. Geodetic Network

There are various GNSS units that can be used to establish the geodetic network. The Trimble Zephyr 2 GNSS and Leica GS15 Smart GNSS Receivers are recommended for establishing a GNSS control network (figure 5). Horizontal displacements can be measured using an industrial-grade total station, such as the Topcon MS05AXII, which has a 0.5" angular accuracy and 0.5mm range accuracy, combined with specifically designed prisms and reflective targets to achieve maximum accuracy in validating potential displacements. Vertical motion can be measured using a high-precision digital level, such as the Leica DNA03. The leveling campaign was carried out using Invar Barcode Staffs, achieving a vertical accuracy at the order of 0.3mm/km [20, 22].

Figure 5: Trimble Zephyr 2 GNSS (left) and Leica GS15 Smart GNSS Receivers (right) for establishing a GNSS control network

3.6 Ground Sensors

Monitoring of kinematic, hydrological, and climatic parameters plays a significant role in creating 3D models and simulations. Geotechnical and environmental factors enable the correlation of geo-hazard events with their triggering mechanisms and assist in identifying the causal parameters for geo-hazard monitoring and simulation [52-54]. However, geotechnical instruments for subsurface movement [23]. Most sensors for measuring earth pressure, pore water pressure, ground temperature, and vibration are point (discrete) sensors. GB-InSAR is a ground-based system that works with the same principles as space-borne sensors for monitoring ground deformation phenomena. GB-InSAR devices allow the assessment of ground deformations of faster landslides, thanks to the possibility of realizing higher frequency measurements [55, 56]. A GB-InSAR can also can be placed in front of steep slopes, which are in most cases not visible from space-borne platforms. Fiber Bragg grating (FBG) sensors can be used to measure variations of temperatures, displacements, loads, earth pressures, pore water pressures and soil moistures with high accuracy [57]. FBG sensors are still in their infancy and therefore are more suitable to be incorporated into geotechnical instrumentation to ensure accurate and real-time measurement. Capacitive sensors, which measure soil moisture levels by capacitive sensing instead of resistive sensing like other types of moisture sensor, are often used as they are made of a corrosion resistant material, giving them a long service life. Piezometers are designed to measure pore-water pressure. Piezometers in durable casings can be buried or pushed into the ground to measure the groundwater pressure at the point of installation. Water levels in the piezometer can either be logged manually (low temporal resolution) or automatically (high temporal resolution) and can be used to calculate pore-water pressures within the screened interval of the piezometer tip. Accelerometers are used to measure acceleration force, such as tilt. Typical accelerometers are made up of multiple axes, two to determine most two-dimensional movement with the option of a third for 3D positioning. Any acceleration caused due to movement in any of the axes is detected by the accelerometer. Crack meters measure the displacement between two points on the surface that are exhibiting signs of separation. A variety of other crack meters including Carlson and vibrating-wire sensors, dial gages, and mechanics feeler gages may be used to measure movement of cracks. Inclinometers are used to monitor subsurface movements and deformations for long-term, precise monitoring horizontal displacements along various points on a borehole and also to monitor the rate of movement. Tiltmeter stations proved efficient in monitoring slope stability in highly active geological environment and continue to act as substantial part of mine monitoring system. Tiltmeters are commonly attached to a surface (internal or external) of a structure and measure vertical rotation of the surface. Extensometers consist of one or more rods anchored at different depths in a borehole and a reference head at the surface. They are commonly installed vertically to measure vertical movement of the reference head relative to the anchor zone(s). They are accurate and can be used for quick and accurate measurement of relative distances between pairs of reference points on the surfaces of structures.

4. DOCUMENTATION

In order to support field monitoring, geometric documentation of the area is performed using a laser scanner, UAV systems and photogrammetry. This data will be supported and geo-referenced using a geodetic network based on total station and level measurements. The focus of the documentation is the reconstruction of the cross-sections over the identified areas of the demonstration site in order to investigate possible changes in the vertical and horizontal profiles of the remains.

Figure 6: UAV during PROTHEGO campaign

UAVs provide an affordable, reliable and straightforward method of capturing cultural heritage sites, thereby providing a more efficient and sustainable approach to documentation of cultural heritage sites. Under the framework of the PROTHEGO project, hundreds of images of the Choirokoitia site were taken using a UAV with an attached high resolution camera. As part of the locale-scale monitoring of the Choirokoitia demonstration site in the PROTHEGO project, a UAV with an attached 20MP camera was used to acquire images over the site with fixed ground control points for geo-referencing in order to produce a photogrammetric ortho-image of the demonstration site and also for comparison over temporal intervals [54]. The images were processed using photogrammetry, where the digital images acquired from the UAV are interpolated in order to create high resolution, scaled and georeferenced 3-D models from them.

Images were taken using UAVs on 29 October, 2016, 2 February, 2017, 11 November and 8 March, 2018, with approximately 450 images taken of the Choirokoitia site during each UAV flight. Ground Control Points (GCP) were applied to correct the scale and geo-reference the model. The images were then pre-processed by removing the lens distortion and then processed using the Agisoft Photoscan Professional software. Figure 7 features the Orthophoto of Choirokoitia site 29 October, 2016, including the resolution of detail.

Figure 7. Ortho-photo of the Choirokoitia site, with resolution of 2.26 cm/pix

All clear images with sufficient overlap were included in the processing in order to generate a dense point cloud of the Choirokoitia site. The 3D point cloud generation for all four monitoring surveys is shown in Figure 8.

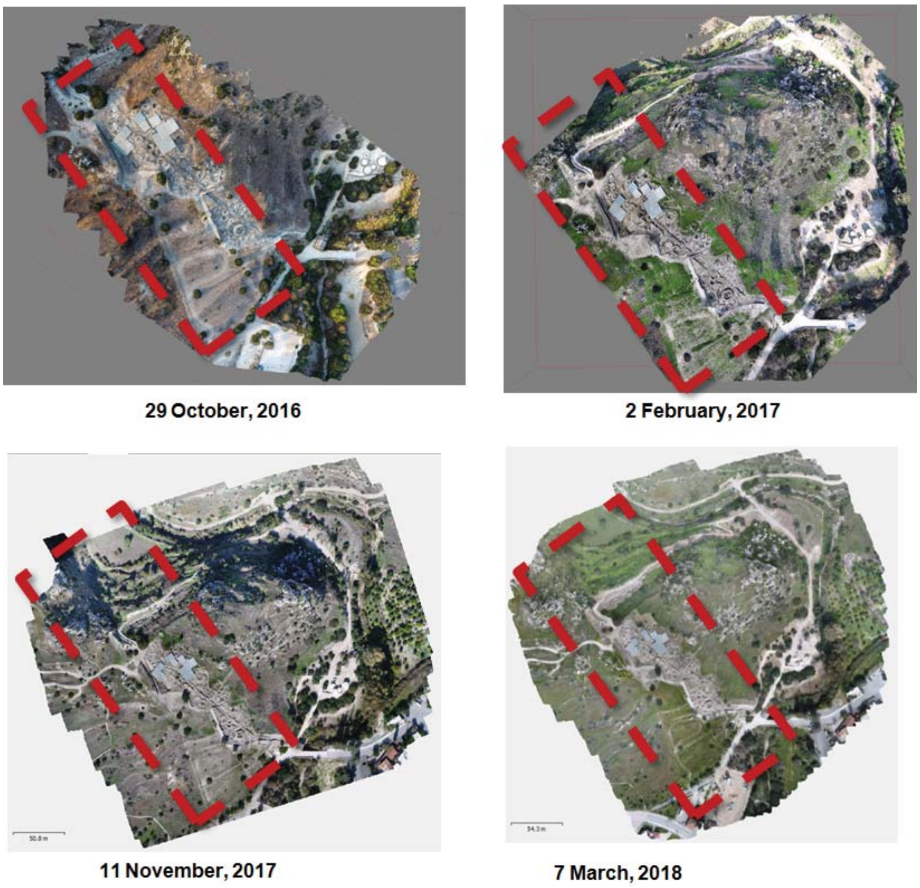

Figure 8. Point cloud generations of Choirokoitia site (outlined in red)

As is evident from Figure 8, there was a dramatic difference in the level of vegetation present at the site on the dates that the images were acquired. The October 2016 and November 2017 images show sparse vegetation while the images acquired in February 2017 and March 2018 show significantly more vegetation present at the site. As it was easier to identify vegetation in the images acquired in the winter campaign due to the colour and morphology of the vegetation, masking was done in order to subtract the vegetation from the model in order to generate the DEM of the ground surface. This was done by using interpolation of the areas where the vegetation was previously present using the images acquired in October, 2016 and February 2017. Following, a contour map of the area was generated using stitch imaging using the DEM model without vegetation (figure 9).

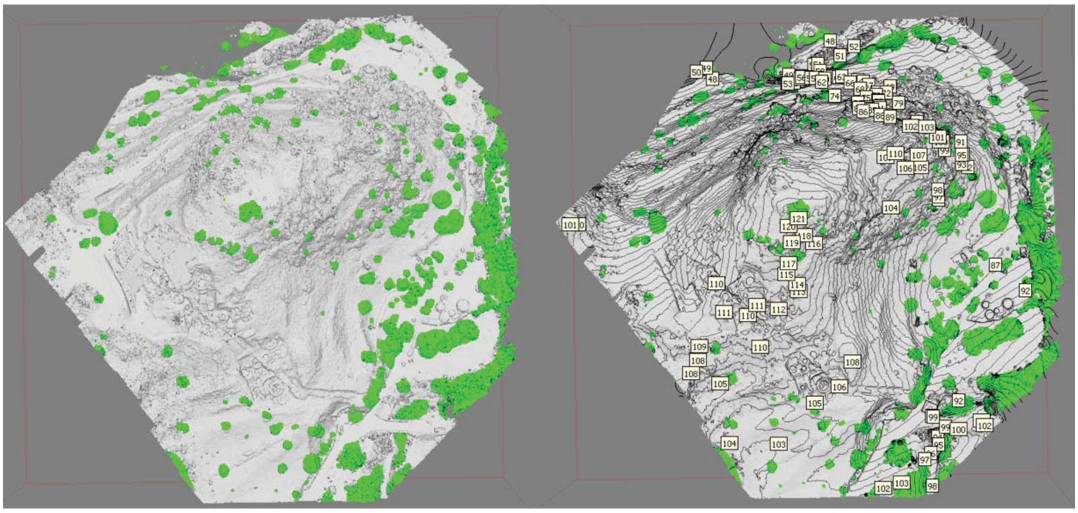

Figure 9. Vegetation Subtraction and contour generation

Digital Elevation Models (DEMs) were generated to examine any possible changes in the case study area over time. Figure 6 features the DEMS generated based on the images from February, 2017, November, 2017 and March, 2018. As is evident in Figure 10, there is a slight shift at the top peak of the hill.

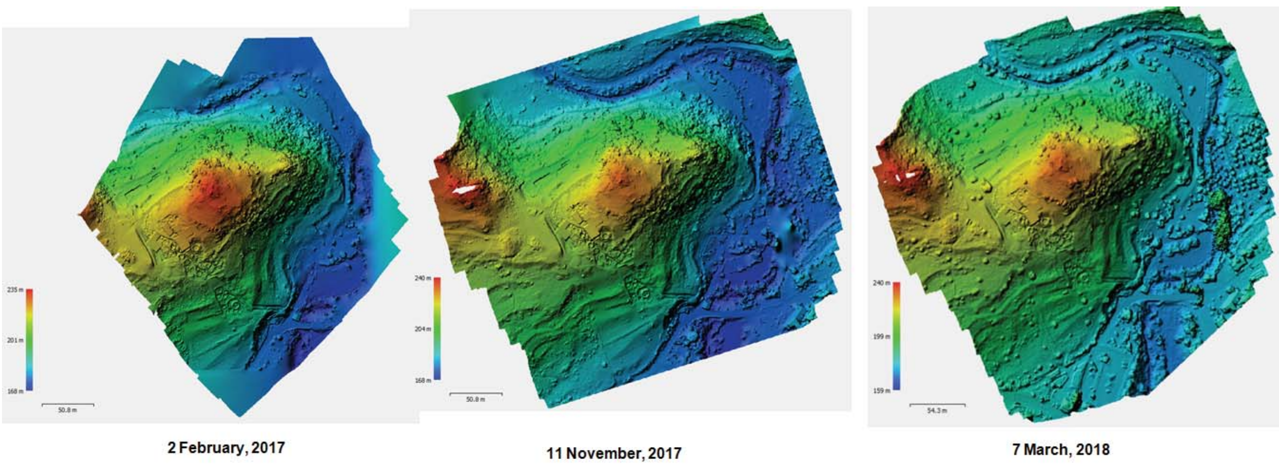

Figure 10. DEM models of the Choirokoitia site

The final 3D model of the Choirokoitia site is presented in Figure 11.

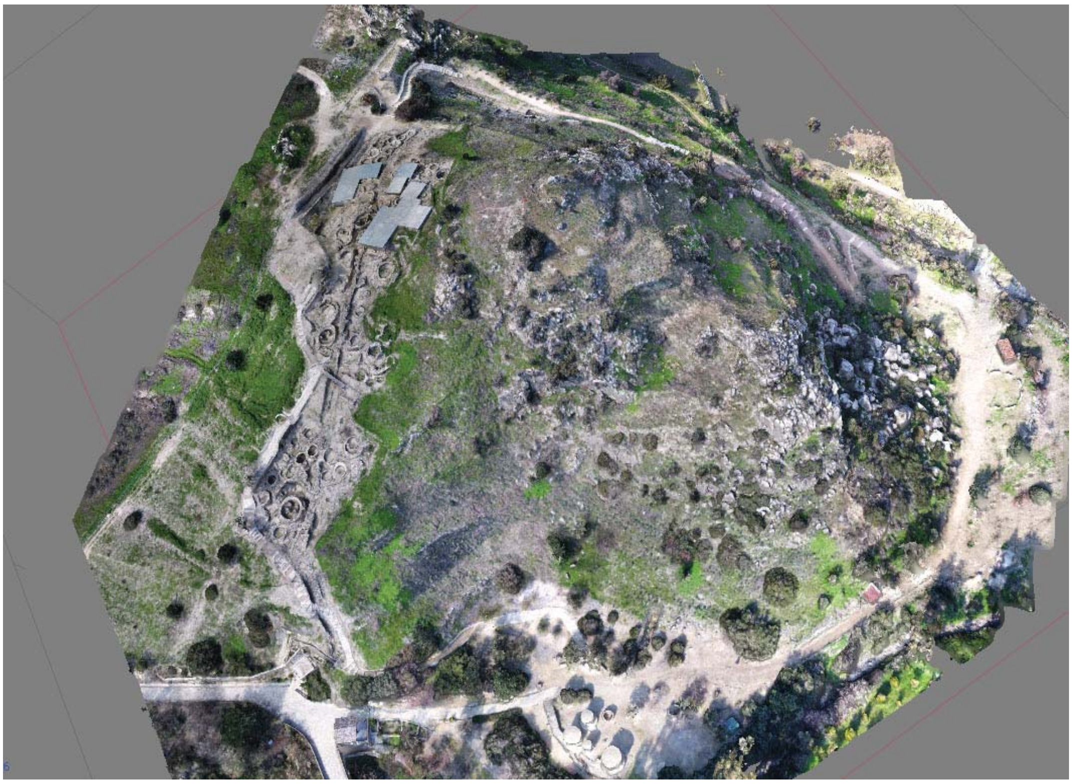

Figure 11. 3D model of the Choirokoitia site generated with UAV images

4.1 Results

Table 1 features the results of the GNSS control network during the study time frame. There were 4 GPs sites which measured displacement east (DE), Displacement North (DN) and Displacement Up (DU). The coordinates used are based on the Cyprus Local Transverse Mercator projection system (LTM) which is based on the Datum Cyprus Geodetic Reference System of 1993 (CGRS93) that uses the ellipsoid WGS84.

Table 1. Results of GNSS Control network

Site	Coordinates	DE	DN	DU
GPS1	231524.820 / 352001.675	+0.0023	-0.0025	-0.0027
GPS2	231314.725 / 351974.690	+0.0022	-0.0001	+0.0017
GPS3	231344.434 / 351922.148	+0.0000	+0.0000	+0.0000
GPS4	231453.791 / 351980.692	+0.0024	+0.0001	**-0.0203**

The results of the GNSS control network found a change of 2mm during the 24 months of the monitoring period of the site, which is indicated in bold in Table 1. As well, a PSI analysis was conducted of the Choirokoitia general area to determine any micro-movements in the area. For the PSI analysis 26 Cosmos Skymed SAR images from the years 2011-2017. For the dates defined, the points exhibit an average of 0.33 mm rate of movement per year (velocity). The results of the PSI analysis found displacement at the same area as the GNSS control network. Longer-term monitoring of the site is required in order to diagnose the severity of the displacement.

5. CONCLUSIONS

The case study of Choirokoitia, Cyprus provides an example of how to detect and analyze deformation phenomena for monitoring and predicting geo-hazards using InSAR ground motion data and field survey techniques to measure and document the extent of damage of the natural hazard on the cultural heritage site. The InSAR data, GNSS, total station and level were used to measure the micro-movements, while the UAV and photogrammetry are used for documentation purposes and 3D modeling comparison. PSI analysis and GNSS Control Network of the cultural heritage site provide the ability to identify displacement as a result of ground movements, which indicates the need for longer-term monitoring of the site to diagnose the severity of the geo-hazards. Local-scale monitoring data is the base for the development of geological and geotechnical modelling of the investigated sites, which will provide evolution models for the deformation processes affecting the heritage sites in order to recognize the best mitigation strategies and to evaluate the effectiveness of these actions for cultural heritage protection.

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Digitization issues in documenting cultural heritage with drones: case study of Foinikas, Cyprus

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ABSTRACT

This paper will examine the use of traditional photogrammetry and LIDAR for documenting cultural heritage site. The case study area was Foinikas village, in the Limassol district of Cyprus, which dates back to the 11th century and has been abandoned from 1960, following the construction of the nearby Asprokremmos dam. Traditionally, photogrammetry has been used for documentation, by processing aerial images acquired from UAVs. However, with the recent development of new lightweight LiDAR scanners, it is now possible to mount professional grade LiDAR sensors on UAVs, which can be used to document areas with high accuracy. In this study, the abandoned village of Fionikas was documented using both photogrammetry using an RGB camera and a LiDAR scanner attached to a UAV. The results of the study found that both methods used provided high accuracy in the documentation of the site.
The present paper is under the auspices of the ATHENA project, which receives funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691936. Work programme H2020 under "Spreading Excellence and Widening Participation", call: H2020-TWINN-2015: Twinning (Coordination and Support Action).

Keywords: UAV, photogrammetry, LIDAR, Cultural heritage, documentation

1. INTRODUCTION

LiDAR and Photogrammetry technologies can be used to document cultural heritage sites. Photogrammetry use captured images to make measurements[1]. Traditional photogrammetry uses two different images of the same area on the ground, which are displaced by a 'baseline', allowing one to use triangulation to discern elevation [2]. The weakness of this is that to measure elevation, a "ray" from each of the two images had to converge at the ground point to be measure. Photogrammetry can only create points based on what the sensor of the camera can detect illuminated by ambient light, essentially taking a complete 'snapshot' of the scene at one moment [1-3]. LiDAR (Laser Imaging, Detection and Ranging) laser scanning use lasers to enable measurements. The lasers are distinguished from other light sources by their coherence, which is typically expressed through the output being a narrow beam of light. UAV LiDAR scanners has the distinct advantage of requiring only a single ray to measure elevation. The main advantage of LiDAR is its ability to penetrate through vegetation, which is nearly impossible using traditional photogrammetry [1-4]. UAV LiDAR is also required to successfully model narrow objects such as transmission lines or sharp edge features, such as roof edges, even though recent photogrammetry algorithms can provide much denser models as well as natural color point clouds. Lidar laser scanners can be attached to a UAV to measure the height of points in the landscape below the UAV and can capture hundreds of square kilometers in a single day. By measuring 10-80 points per square meter, a very detailed digital model of a landscape can be created. However, LiDAR works by scanning progressively through the scene, so any discrepancy in its movement during the scan will distort the resulting data [2,3].

In this paper, the Eratosthenes Research Centre of the Cyprus University of Technology and the LidarUSA company documented an abandoned village through the use of traditional photogrammetry using aerial images and with LiDAR scanners attached to UAVs in order to determine which method was more effective. The study area was the abandoned village of Foinikas in the Limassol District of Cyprus, which dates back to the 11th century. Foinikas village was a military command centre for the Knights Templar during the 12th century. The recent series on the History Channel "Buried- Knights Templar and the Holy Grail" features the village of Foinikas and focuses on its importance for the Knights Templar (figure 1). The study was conducted parallel to the filming of the episode featuring the village of Foinikas as a potential stronghold of the Knights Templar in Cyprus.

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WHAT REALLY HAPPENED TO THEM?
BURIED
KNIGHTS TEMPLAR AND THE HOLY GRAIL

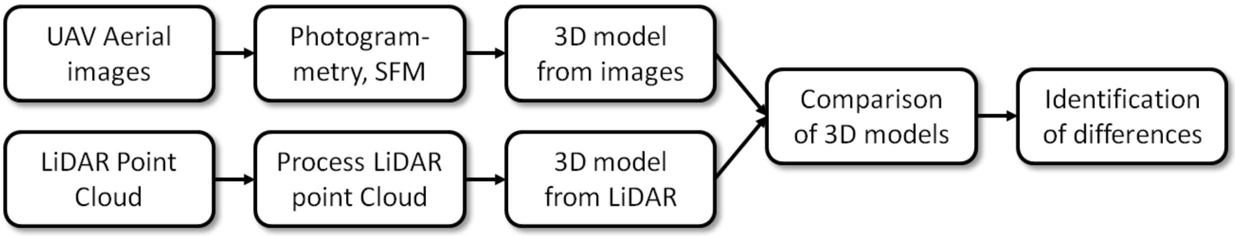

UAV Aerial images
Photogram-metry, SFM
3D model from images
LiDAR Point Cloud
Process LiDAR point Cloud
3D model from LiDAR
Comparison of 3D models
Identification of differences

Figure 4. LiDAR HDL-32E laser scanner attached to UAV

3.3 Photogrammetry

Nearly 200 aerial images were captured with the camera loaded onto the UAV and were then processed using photogrammetry. The first step in the program's procedure is called Structure from Motion (SFM). At this stage the software analyses the dataset, detecting geometrical patterns in order to reconstruct the virtual positions of the cameras that were used. Figure 5 indicate the location of the image, while Figure 6 features a thumbnail view of the image that was used for the particular point.

The second step involves the creation of a complete geometry of the scene using a dense multi-view stereo reconstruction. At this stage the dataset of images are employed to produce a high- resolution geometry of the surface. This step successfully creates a 3D model, also known as a Digital Surface Model (DSM). The processing began with the ortho-mosaic production from multiple images, that was then used for DTM production from which a contour map can be generated. The completed alignment is then used to develop a dense point cloud which uses it to create a surface which allows draping of the imagery over the model by creating and building a texture from the original images and overlays the imagery onto the model mesh [8]. The software then builds a polygon mesh and calculates a texture for the mesh.

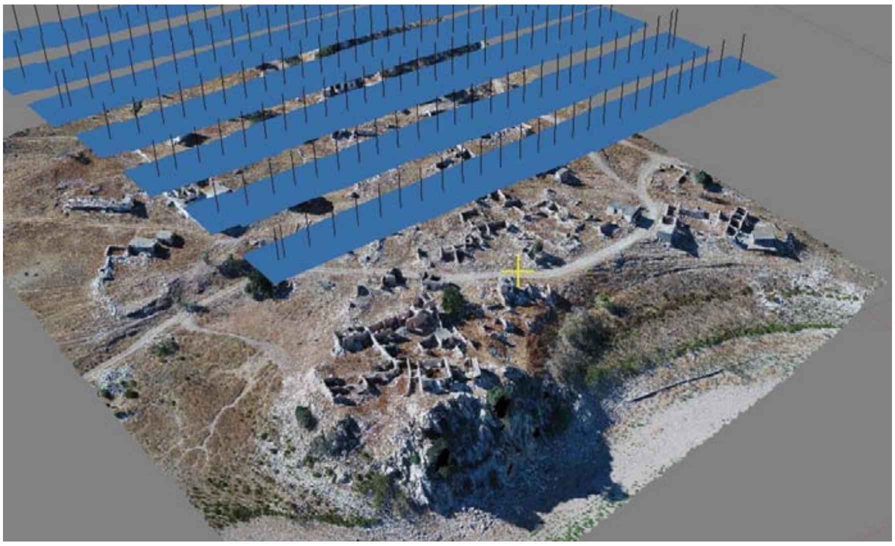
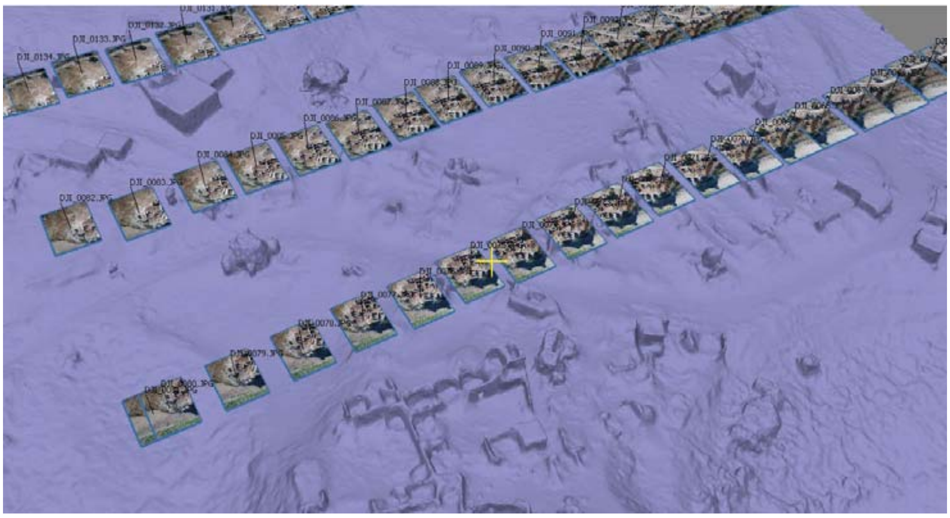
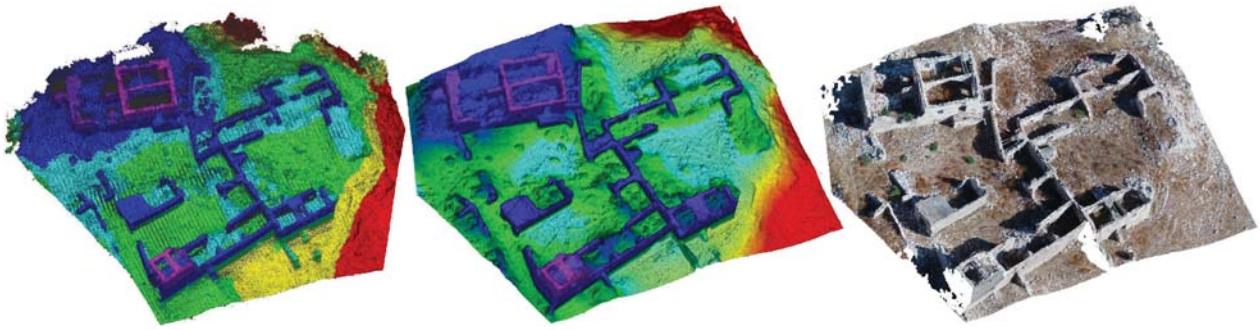
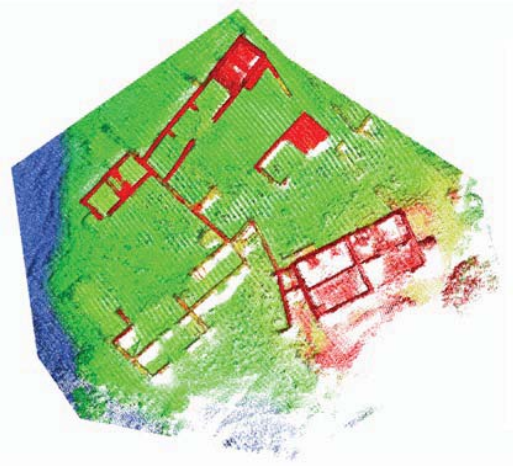
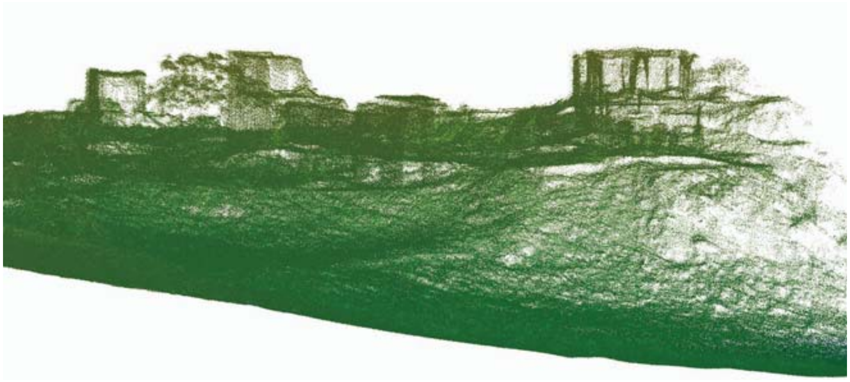


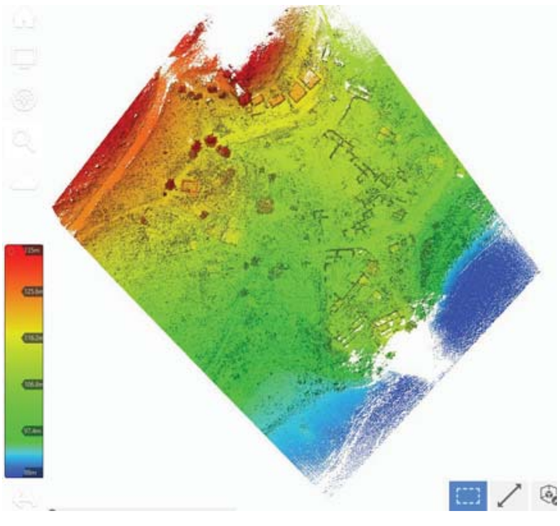
Figure 5: Positions of the camera over study area











Photogrammetry is able to generate full-color 3D and 2D models (in the various light spectrum) of the terrain that is easier to visualize and interpret than LiDAR. The main outputs of photogrammetric surveys are raw images, ortho-photos, DEM and 3D points clouds created from stitching and processing hundreds or thousands of images. The outputs are very visual with a pixel size of 1cm. [6]. Figure 11 features the DSM and the ortho-photo of the Foinikas study area which were generated using photogrammetry.

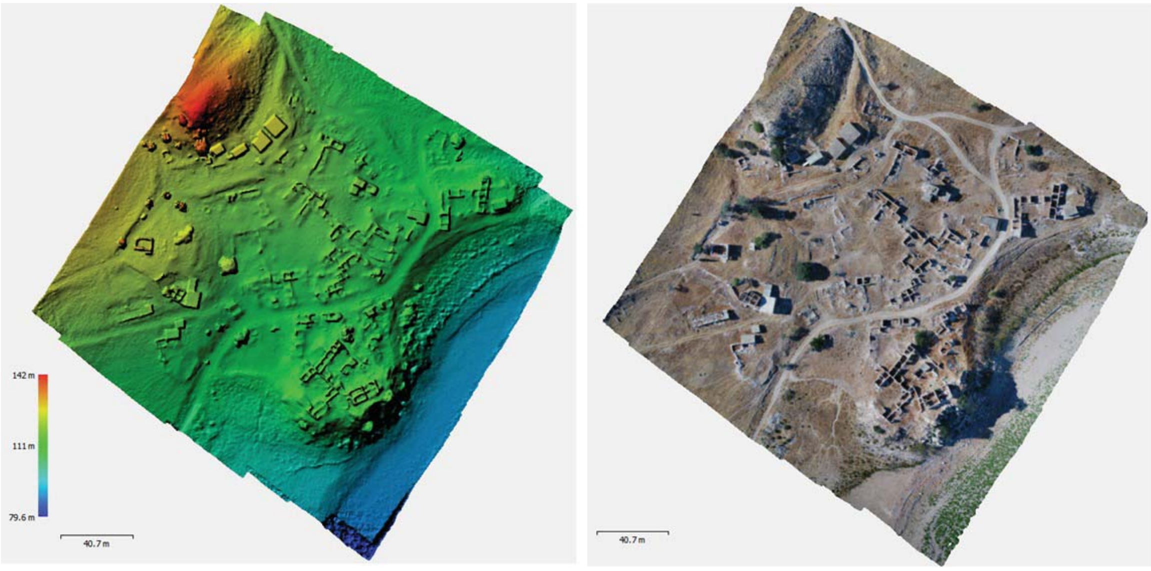


Figure 11: Left - DEM of study area; Right - Ortho-photo of study area

The completed orthophoto of the study area is featured in figure 12.

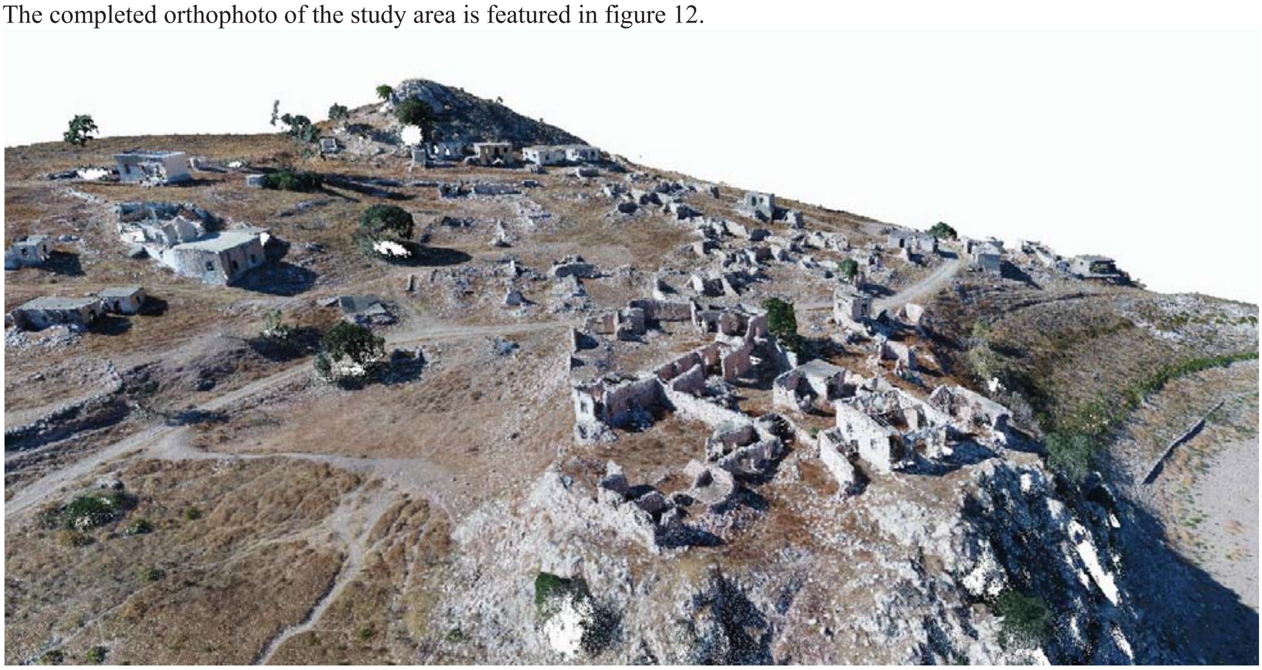


Figure 12: Ortho-photo of Foinikas site using photogrammetry

The two models were overlapped in order to identify any differences between the two surveys. In Figure 13, the red points refer to the model generated using photogrammery from aerial while the blue points refer to the model from the UAV LiDAR. It is evident that the LiDAR did not show the vegetation due to the ability of the laser to penetrate through vegetation and has less noise, as indicated by the blue points. This comparison indicates that even though both techniques can create an accurate 3D model, the UAV LiDAR was more accurate in documenting the study area.

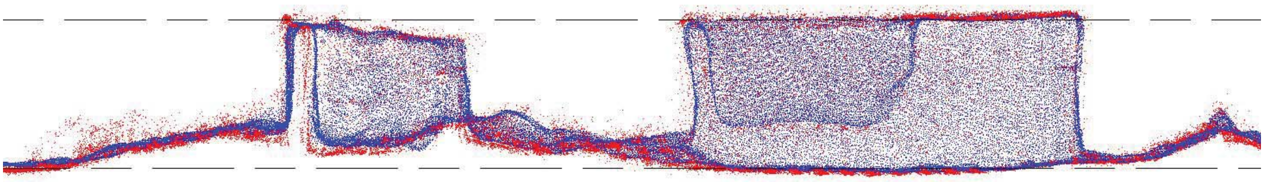


Figure 13. Comparison of two point clouds showing a partial section through the buildings

5. CONCLUSIONS

The aim of the paper was to compare the documentation of the study area using both UAV LiDAR and traditional photogrammetry. The results found that the UAV LiDAR provided more detailed and accurate documentation, especially in cultural heritage sites. An additional benefit of using UAV LiDAR for documentation is that the method is able to penetrate through vegetation to generate a precise documentation of the site. In this study, traditional photogrammetry had similar results as the UAV LiDAR, with the advantage that it is a more cost-effective method as it can be used with smaller UAVs. However, photogrammetry is not effective in penetrating vegetation canopies, of which the LiDAR system has as an advantage for archaeological sites that are covered in vegetation. Over time, UAV Lidar systems are becoming less expensive with additional capabilities and can be combined together with photogrammetry and other sensors for optimal documentation of cultural heritage sites.

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The innovative documentation of cultural heritage using H-BIM: case study of Asinou church

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ABSTRACT

The study examines the documentation of the Asinou Monument within the auspices of the H2020-SC6-R&I-INCEPTION project. The project realises innovation in 3D modelling of cultural heritage through an inclusive approach for time-dynamic 3D reconstruction of artefacts, built and social environments. It enriches the European identity through understanding of how European cultural heritage continuously evolves over long periods of time. In this study, digital techniques for data acquisition and methodologies for data processing were examined using the Asinou Church as a case study. Asinou Church is a 11th century shrine to the Virgin Mary, located in the Troodos Mountains of Cyprus and is a UNESCO World Heritage Site and contains some of the finest Byzantine wall paintings in Cyprus which date between the 12th to the 17th century. Different techniques, such as photogrammetry, laser scanning, drones, video and photographs were used for the data acquisition of all features of the church, which were then processed to create a 3D model and document the church using Building Information Modeling (BIM). The church was digitally reconstructed in a 3D BIM model, where it was then processed to produce a Heritage building Information Model (H-BIM) in order to create an information database for further study.

Keywords: H-BIM, EU-H2020 INCEPTION, Digital Cultural Heritage, Remote Sensing, BIM, 3D model, UNESCO WHL, 3D reconstruction, Asinou church.

1. INTRODUCTION

The study examines the interior and exterior documentation of the Asinou Monument within the auspices of the H2020-SC6-R&I-INCEPTION project for the development of a digital platform to interact with the end-user within a series of visual data and metadata regard-ing the monument. The INCEPTION project (www.inception-project.eu) realises innovation in 3D modelling of cultural heritage through an inclusive approach for time-dynamic 3D reconstruction of artefacts, built and social environments. INCEPTION solves the shortcomings of state-of-the-art 3D reconstruction by significantly enhancing the functionalities, capabilities and cost-effectiveness of instruments and deployment procedures for 3D laser survey, data acquisition and processing. It solves the accuracy and efficiency of 3D capturing by integrating Geospatial Information, Global and Indoor Positioning Systems (GIS, GPS, IPS) both through hardware interfaces as well as software algorithms. INCEPTION methods and tools result in 3D models that are easily accessible for all user groups and interoperable for use by different hardware and software. It develops an open-standard Semantic Web platform for Building Information Models for Cultural Heritage (HBIM) to be implemented in user-friendly Augmented Reality (VR and AR) operable on mobile devices.

In this case study of the Asinou Church in Cyprus, the semantic development of the different entities and objects that make up the exterior and interior of the church, including wall frescoes and the 3-D space, create a knowledge base for the research of the Church. The idea of using digital technology to document cultural heritage in all aspects, both tangible and intangible heritage within a structure, creates a dynamic database and valuable resource to better understand the cultural heritage monument, as end-users will be able to access the information from the digital platform at any time [1-5].

Different techniques, such as photogrammetry, laser scanning, unmanned aerial vehicles (UAVs), video and images were used for the data acquisition of all features of the church, which were then processed to create a 3D model and document the church using Building Information Modeling (BIM). The church was digitally reconstructed in a 3D BIM model, where it was then processed to produce a Heritage building Information Model (H-BIM) in order to create an information database for further study.

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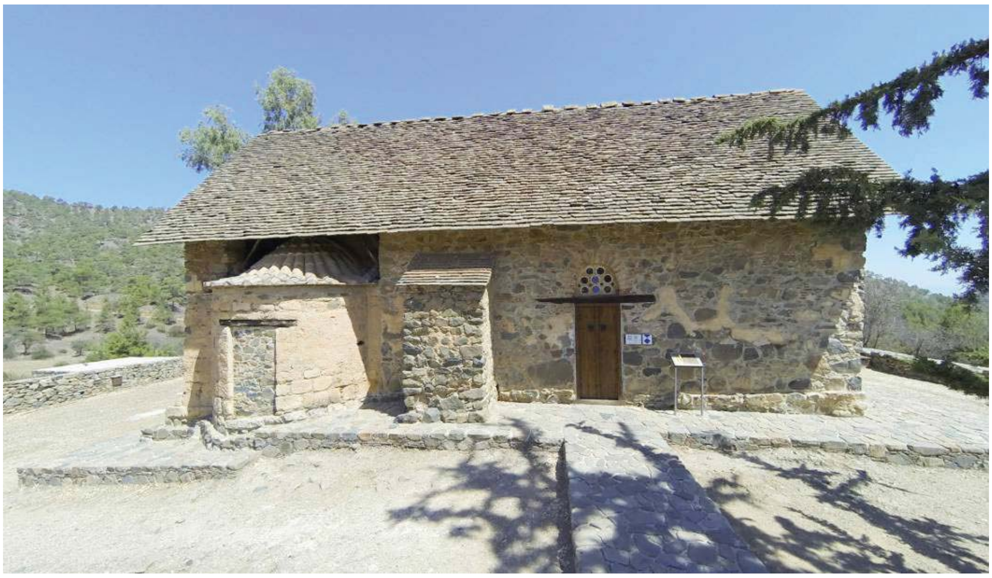



Documentation with UAV & laser scanner (Exterior)
Documentation with camera - Photogrammetry (Interior)
3D Modeling
HBIM Model with 3D to 7D data

Figure 4. Model of Asinou Church created with 3D laser scanner

The interior of the church was photographed using a Canon 50D camera. Over 2,000 images were taken with an overlap of 80%. Photogrammetry software was used to conduct the image processing (Figure 5). The software is able to interpolate digital images in order to create high resolution, scaled and georeferenced 3-D models from them. Its functions include aerial triangulation, polygonal model generation (plain/textured), setting coordinate system, georeferenced DTM generation and georeferenced orthomosaic generation [16].

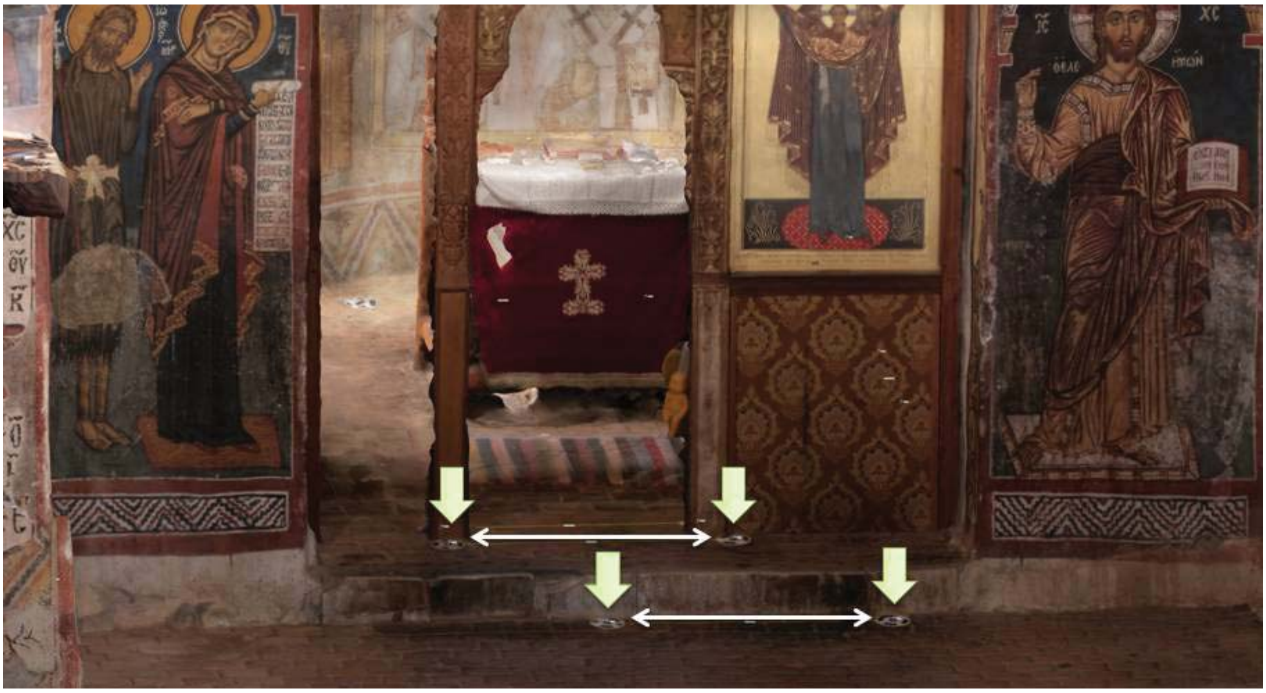
Figure 5. Interior of Asinou Church, acquired from camera images processed through photogrammetry

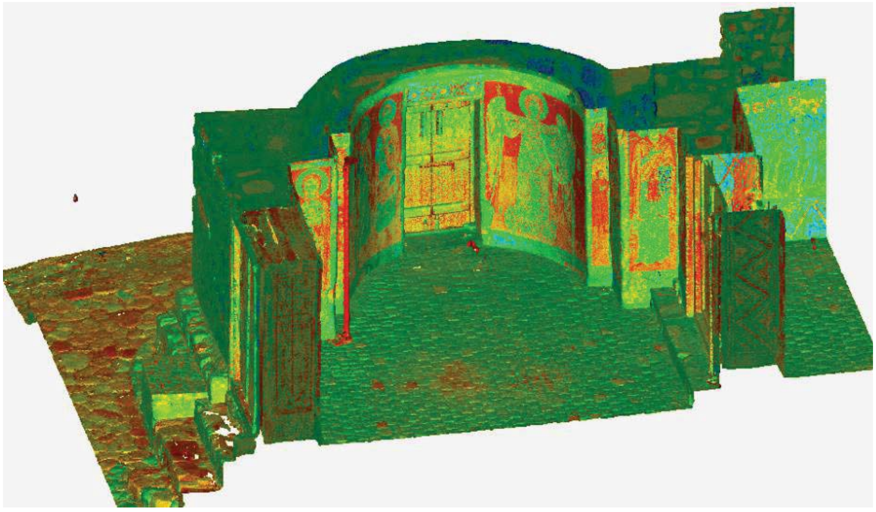
The primary step in the program's procedure is called Structure from Motion (SfM). At this stage the software analyses the dataset, detecting geometrical patterns in order to reconstruct the virtual positions of the cameras that were used, align the images, including building a sparse point cloud (tie points). The software automatically aligns images based on pairing of features (e.g. sand grains of different colors, etc.) and creates a "sparse cloud" of elevations based on these points. The completed alignment is then used to develop a dense point cloud which uses it to create a surface which allows draping of the imagery over the 3D model by creating and building a texture from the original images and overlays the imagery onto the model mesh [20]. The software then builds a polygon mesh and calculates a texture for the

mesh. Due to the high resolution images from the camera and the dense overlap, the mesh of the model created was so dense that surface features of the model that were invisible to the eye were pronounced within the model.
Figure 6 features the same image in 4 different aspects. The upper left quadrant features the fresco, as it is evident to the naked eye. The lower left quadrant is the result of the 3D surface model, which features the halos that the artist constructed on the plaster wall using paint. The upper right quadrant shows the mesh model, where the halos are again quite visible and the lower right quadrant features the point cloud of the model.

Figure 6. Details of fresco, using camera images, 3D model, mesh and point cloud

The secondary step involves the construction of the geometry of the area using a dense multi-view stereo reconstruction. The dataset of images are employed in order to produce a high- resolution geometry of the surface. This step successfully creates a 3D model. The processing began with the ortho-mosaic production from multiple images, that was then used for DTM production from which a contour map can be generated. All photos can be included in processing or it is possible to select a sub-set of images on key sites with the study area for more detailed analysis ensuring sufficient overlap and ground control points (GCPs) allow for this. Figure 7 indicates the GCPs located inside the church, which were used to reference the 3D model in order to provide a scale to the interior of the model. The GCPs were also geo-referenced in order to combine the interior and exterior point clouds in order to create the entire church model.





3.3 Building Information Modelling (BIM)

Building Information Modelling (BIM) is an intelligent 3D model-based process that involves the generation and management of digital representations of physical and functional characteristics of places. BIM design tools allow extraction of different views from a building model for drawing production and other uses. BIM is used for design and management of projects in the built environment industry. BIM is a collaborative model where multiple team members can collaborate on a project at the same time, thereby increasing efficiency and accuracy. After the BIM model was constructed, drawings of the plans, elevations and sections of the church can be generated directly from the BIM model for documentation purposes. Also, information such as material, color, height, thickness, etc. can be added to each component in the BIM database. Sections of the 3D BIM model are featured in Figure 9.

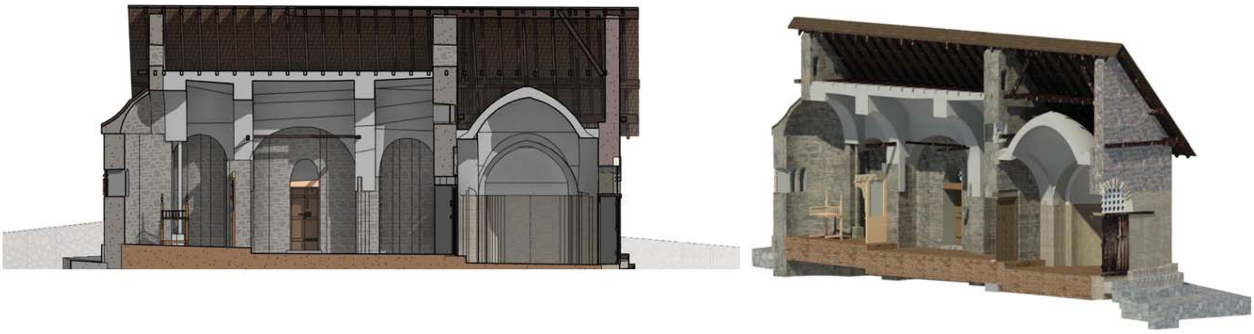
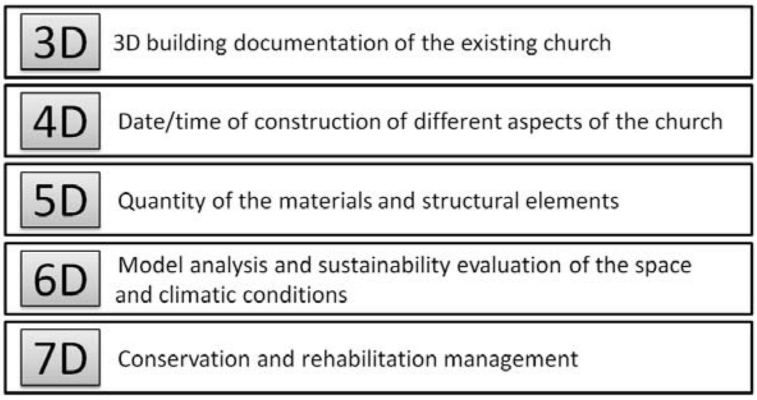


Figure 9: Sections of the 3D BIM model

BIM workflows provides the capability to document cultural heritage buildings in order to facilitate the existing building model structure with the information collected from the cultural heritage building in order to create an integrated HBIM (Heritage Building Information Model). HBIM includes all the information and parameters from the cultural heritage building, including building components, structural elements, materials and semantic information. The development of such an information management model was the basic tool in order to construct and develop the H-BIM of the Asinou Church. The resulting 3D HBIM has the ability to manage all the building information as a church and as a cultural heritage monument.

The 3D BIM model resulted from the survey data using laser scanners and photogrammetry documented the existing condition of the Asinou Church with a scale of 1:1 in order to integrate all the metadata collected from the building. From this, a 3D model was created for the interior and exterior of the church. The two models were combined together in order to create an accurate 3D model of the entire church. Following the creation of the 3D model, the point clouds were inserted into the BIM software using Revit in order to create a 3D model. All the information from the frescoes, materials and textures were documented in the BIM model in order to create a database of all the information acquired from the 3D documentation methodology. The building elements of the church were documented and the metadata was attached to the 3D model. Also, the materials and structural elements were modelled within the BIM model in such a way that they could be quantified. The 3D model can be used to conduct an analysis and sustainability evaluation of the space and climatic conditions, as well as for the conservation and rehabilitation management of the Church. Figure 10 features the BIM dimensions which can be implemented on the Asinou Church.


3D
3D building documentation of the existing church
4D
Date/time of construction of different aspects of the church
5D
Quantity of the materials and structural elements
6D
Model analysis and sustainability evaluation of the space and climatic conditions
7D
Conservation and rehabilitation management

images from the site permitted the data processing and the development of a point cloud of the church [22]. The HBIM approach for documenting such cultural heritage monuments is the solution for managing tangible and intangible information that creates the narrative of the monument. The HBIM acts as a source of information which provides valuable data without the need of visiting the monument [5].

The process of documenting, creating and implementing the methodology of BIM for cultural heritage monuments provides the opportunity of capturing the cultural heritage information for managing a HBIM holistic approach. In the case of the Asinou Church, the presence of the Byzantine frescoes in the interior space created the need for the collection of data in order to integrate the story of each fresco into the building information regarding image, geometry, color, texture, etc. The entire church was modeled using HBIM so that all the frescoes covering the walls and ceiling of the church could be documented. Using the Revit software, drawings including floor plans, elevations and sections of the church were generated. A database was created to include information regarding the structure, including wall height, thickness, material, etc. This provided a valuable source of documentation of the church, for future restoration and maintenance works. Also, the documentation of the site was important to study possible expansion projects. The elevations are also overlaid with the point cloud to provide additional information on the building, such as surface texture, color and materials.

5. CONCLUSIONS

In this paper, laser scanning, UAVs and photographic images were used to document the interior and exterior of the Asinou Church in high resolution. The imagery obtained from the UAVs and from the cameras were processed with photogrammetry software to create rapid and automated generation of a point cloud model and 3D mesh model of both the interior and exterior of the Asinou Church, which were joined to form one model. The point cloud generated was then exported in to BIM, in order to produce a detailed BIM model complete with all relevant data of the site. The high accuracy documentation generated from the BIM model can be used for future renovation or conservation activities of the church.

ACKNOWLEDGEMENTS

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STUDY OF ANCIENT MONUMENTS' SEISMIC PERFORMANCE BASED ON PASSIVE AND REMOTE TECHNIQUES

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ABSTRACT

"Engineering structures are designed to be safe. The difficulty one trading in this regard is the desire to construct something for a specific purpose out of a material of which one can never know enough in terms of the material's properties as well as the environment the structure is going to operate in".
Even though this affirmation was initially drawn for modern structures, it however firmly describes the situation of the ancient ones. In the case of ancient monuments, the mechanical properties of the construction materials, their consistency and their homogeneity are highly unknown and can only be determined probabilistically through elaborate testing under legislative and protective to the monuments' restrictions. On the other hand, the environmental (weather) conditions and natural hazards to which those ancient masonry structures were and still are exposed is even more difficult to be determined with precision and thus monitored, but has certainly led to their degradation.
Towards this end, the present study discusses the potentialities of non-destructive passive and remote system investigations of monuments, trying to examine the benefits and drawbacks in relation to the result and in comparison to conventional structural control methods. A selection of the most credible methods for the investigation of monuments is described along with their potential applications.
The scope of this investigation is to acquire information regarding the subsurface condition and consequently the structural system of the monument and anticipate its future behavior in destructive earthquake events. This can be achieved through a simulation model, which can be as realistic as the information obtained and can be updated with more thorough information. To demonstrate the application of this updating process in obtaining the response of the monument, a case study tomb "Tomb 4" from the Hellenistic necropolis of the 'Tombs of the Kings', in

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Paphos Cyprus is examined, recapitalizing thus previous work of the team accomplished on the aforementioned monument. The seismic performance of the monument, located in a moderate earthquake hazard area, will be examined based on passive and remote data acquisition and simulation results will be shown.

Keywords: structural survey; underground monument; cultural heritage; passive and remote techniques; seismic analysis

1. INTRODUCTION

The intrinsic value of built cultural heritage is renown and accepted in all levels of related disciplines. However, ancient monuments are exposed to a variety of factors of anthropogenic and environmental nature, which along with natural aging affect their preservation. On this ground many initiatives in European level have been activated throughout the years, pursuing their protection (UNESCO 1972; Colette 2007). Within this context, a great attention is given to the investigation of the condition of preservation and monitoring of monuments, with the combined use of efficient and non-destructive technological tools, information and computational technologies, various observation floors (from satellite to ground).

The present study concerns the ancient necropolis known as “Tombs of the Kings”. The site dates back to the 4th century BC and is situated in NW Paphos District. Within the necropolis several tombs of the atrium type exist. These were carved out of the solid rock and feature open air porticoes supported by monolithic columns and/or masonry pillars. Many of the tombs incorporate alterations dating to the Roman and Medieval times. The site suffered extensive quarrying activity in modern times, while studies (Barker 2004) indicate that the area might have been simultaneously used as a necropolis and a rock quarry during ancient times. The aforementioned multiple use of the site, along with looting, contributed to the decay of the tomb monuments. Systematic cleaning and excavation of the site took place between 1977 and 1990 by the Cyprus Department of Antiquities. Since then, the funerary constructions preserved up to date have been declared Ancient Monuments, while in 1980 the archaeological site was included in the UNESCO list of World Heritage Monuments.

For this research, Terrestrial Laser Scanning, Ground Penetrating Radar measurements and Finite Element analysis have been merged in an effort of a multilevel analysis and approach of the monument’s state of preservation. These tools provided all necessary information for the development of numerical models and consequently analysis methods seeking possible documentation of the structural preservation of the monuments.

A geotechnical approach of the seismic response of the monument is hereunder considered with special focus, while the fusion of the post-processed results of the GPR and TLS surveys will be a subject of a future publication.

2. METHODOLOGY

The methodology followed for the investigation of the tomb included both in situ examination and desk-based processing. Field work was initiated by detailed visual inspection of the monument and documentation of its current state of preservation. Subsequently, the Terrestrial Laser Scanner (TLS) method was used for the geometric documentation of the tomb, while both TLS and Ground-penetrating radar (GPR) techniques were employed to map the monument’s state of preservation, primarily as far as its structural and superficial condition concerns.

TLS enables the 3D documentation of an object in a predefined distance using multiple laser beams and has thus been used for multiple purposes various applications worldwide (Assali et al. 2014; Ruther & Paloumbo 2012). Due to its enhanced time efficiency and ability to survey complex structures with high accuracy, TLS is increasingly employed in the domain of built heritage. Even though, the post processing of the acquired data for the formulation of a 3D model could be time consuming, the overall benefits of using a TLS for ancient monuments survey are multiple. The documentation of the geometry facilitates the architectural and structural understanding of a monument, while at the same time captures its state of preservation. Subsequently, a realistic 3D model of a monument and/or its environs, it is of

great value for restoration and conservation interventions, considering both aesthetic and practical implications (Ruther et al. 2009).
GPR is a RAdio Detection And Ranging technology designed to detect and localize targets hidden below the air-soil interface or in optically opaque materials. It exploits microwaves, i.e. signals belonging to the portion of the electromagnetic spectrum ranging from 10^8 up to 10^{10} Hz, and the ability of these signals to penetrate into non-metallic objects. Accordingly, GPR can be regarded as a non-invasive geophysical prospecting technology and it is commonly adopted in several applications among which structural surveys, devoted to retrieve information on the internal features of masonry or pillars, including the presence of cracks, voids and defects. In particular, this method is very useful in the field of heritage diagnostics, restoration and conservation (Masini et al., 2007).
A time-domain standard GPR system transmits a modulated time domain pulse and collects the reflected energy as a function of time, which represents the travel-time of the wave along the transmitter-target-receiver path. It is worth noting that the target is a generic variation of the electromagnetic properties (dielectric permittivity, electrical conductivity, and magnetic permeability) occurring into the probed medium. Hence, GPR allows the identification of internal layers as well as the detection of local reflectors referable to decay pathologies such as voids, cracks and fractures (Persico 2014). More precisely, by shifting the transmitting and receiving antennas along a line and joining together the gathered traces at all the antenna positions, a spatial-time image is built, which is referred to as raw-data radargram or B-scan. Being the round-trip travel time a function of the distance occurring among antennas and targets, the radargram provides a distorted image of hidden objects, which appear as hyperbolas whose characteristic features (i.e., vertex and eccentricity) depend on position, shape, size of the objects as well as on electromagnetic properties of the probed medium. As a consequence, advanced data processing approaches, among which microwave tomographic approaches (Soldovieri 2011), are commonly adopted to improve the imaging capabilities and obtain easily interpretable images. Herein, a microwave tomographic approach, which is based on a linear model of the scattering phenomenon underling the GPR survey is exploited (Catapano et al. 2012).

3. CLOSE RANGE SURVEY TECHNIQUES RESULTS

3.1 Terrestrial Laser Scanning survey

For the TLS survey the Leica ScanStation C10 laser scanner was used. The capacity of the machine permits a scanning of up to 50,000 points per second, while the accuracy is of the level of ±6mm/50m distance. The field of view (FOV) of the Scan Station is of 360º x 270º which provides huge flexibility in close-range applications such as the current case study.
For the purposes of the present study the monument was scanned under a medium resolution analysis (i.e. points every 1mm at 10 m distance). Due to the complexity of the monument, six different scan stations were positioned providing equivalent number of point clouds. For registration purposes of the individual point clouds, special reflector targets were used. Coordinates of the targets were estimated using the reflector-less total station Leica 1203+. The Root Mean Square (RMSE) registration error was reduced at 1cm, an acceptable error for the purposed of the present study. The registration of the individual point clouds was based upon the ICP (Iterative Closest Point) algorithm.
Amongst the aims of the TLS survey were to capture the geometry of the monumental complex, to digitally map the cracks present on the vertical walls of the tomb and the columns/pillars, and thus facilitate the monitoring and observation of the phenomenon over the time, in case that changes occur. In addition, through the digital documentation of the monument the state of preservation as for the weathering of the rock surface could be mapped and quantified, supporting any future conservation intervention (Figure 1).

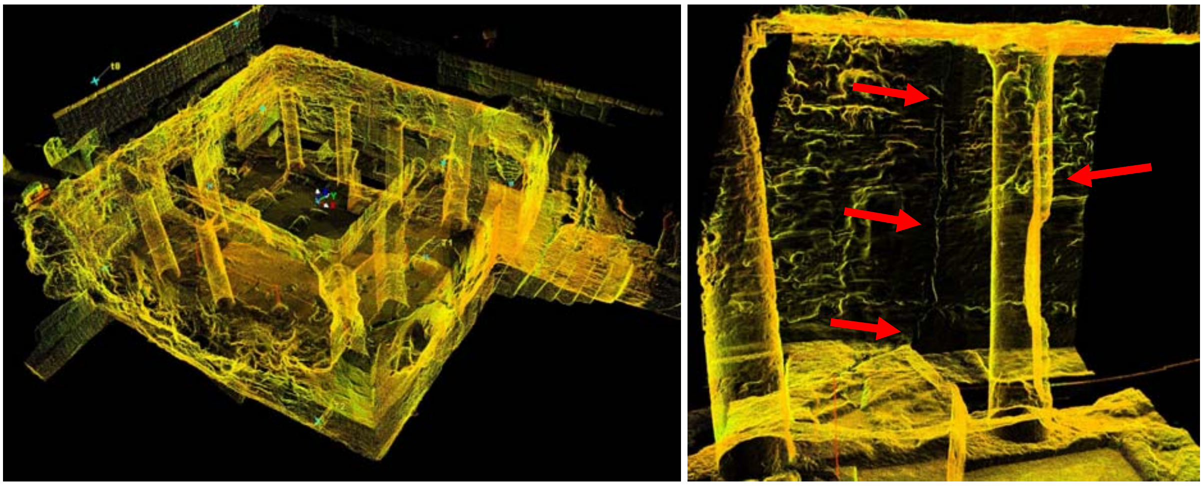

Figure 1. General preview of the point cloud (left); detail indicating cracks along the east wall and column of the tomb (right).

3.2 GPR survey

The GPR survey carried out on the pillars of Tombs of King n. 4, was performed with the time domain Ris Hi-Mod GPR system, manufactured by IDS System, equipped with a single fold shielded antennas, whose nominal peak frequency is equal to 2GHz. All the GPR profiles have been acquired by considering a 32 ns observation window discretized by 1024 time samples for each measurement position. Each column/pillar examined was probed along parallel vertical and horizontal scans along the circumference.

As said, GPR data processing can identify interfaces between the local reflectors referring to voids, fractures or inhomogeneities and improved results are obtained by exploiting microwave tomography. Specifically, we have processed the gathered data by using a linear microwave tomographic approach (Catapano et al. 2012). This approach faces the imaging as the solution of an inverse scattering problem, exploits the Born approximation to define the mathematical model describing the relationship between data (i.e. the gathered radar echoes) and unknowns (i.e. the contrast function, which accounts for the occurring electromagnetic variations) and it adopts the Truncated Singular Valued decomposition to obtain a reliable solution. The output is a spatial map, named tomographic image, showing, pixel by pixel, the absolute value of the retrieved contrast function, whose expression can be given as normalized to its maximum value into the overall investigated region or slice by slice. Accordingly, the significant values identify the location of targets and give information about their geometry. Figure 2 shows the tomographic images obtained by processing data acquired along horizontal scans at different high from the column top. These images allow the clear visualization of localized anomalies, which infer the presence of a number of reflectors referable to cracks and material discontinuities, some of them not visible by means of a visual inspection of the column.

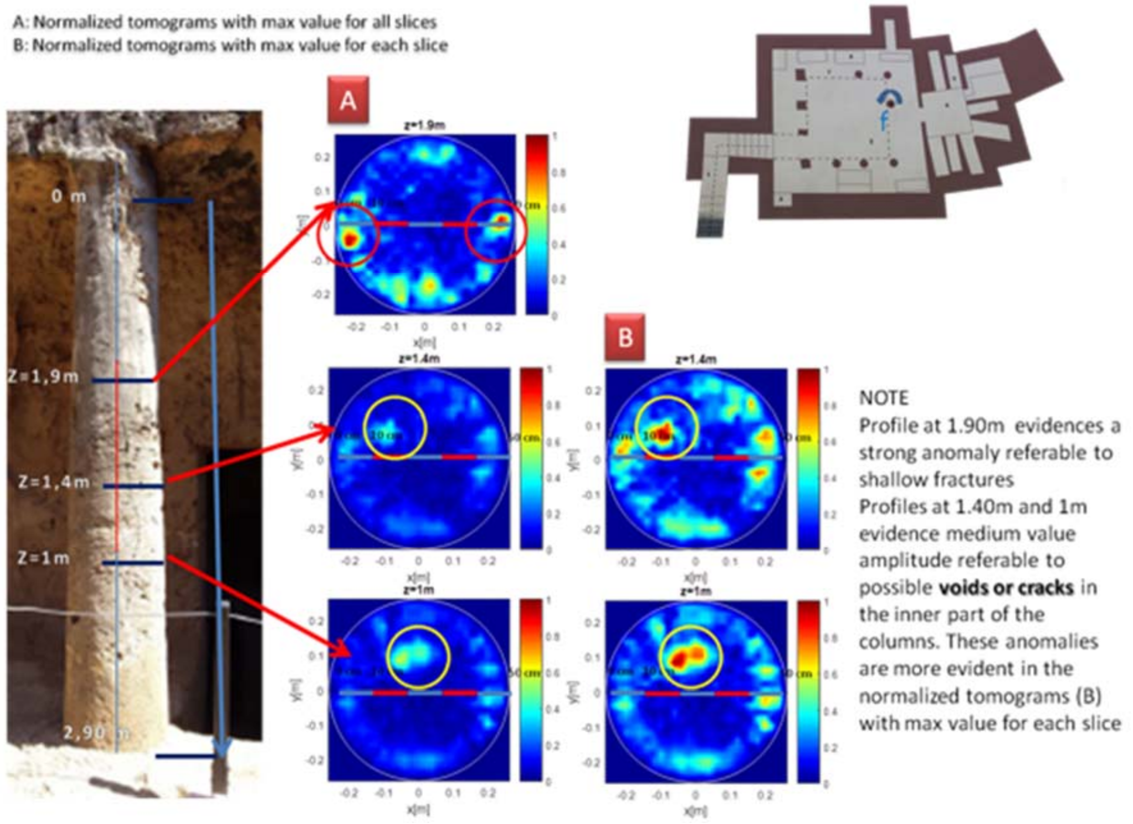

Figure 2. Tomographic images from horizontal scans using GPR

4. ANALYSIS OF SEISMIC RESPONSE

4.1 Finite element modelling

The seismic analysis of underground monuments such as the tomb under study poses a real challenge. Unlike surface structures which are directly subjected to ground excitations and experience amplification of their shaking motion depending on their own vibratory characteristics, underground structures primarily sustain racking deformations/distortions imposed by the seismic motion of the surrounding medium (i.e. soil or rock) (Wang 1993). Focus should therefore be placed on evaluating the distribution of free-field displacements within the ground layers and on examining their effect on the various members of the underground structure (St John & Zahrah 1987).
In light of the above, the seismic response of the ancient tomb is hereby examined using a quasi-static approach. The adopted method involves simulating the effect of an earthquake with an equivalent seismic load that is statically applied to the structure as a distribution of free-field cumulative displacements. For this purpose, a Finite Element (FE) model was developed based on the geometry of the tomb and the geotechnical characteristics of the area, while 1D numerical analysis was performed to calculate the ground deformations generated during seismic motion. It is worth noting that although this methodology has been extensively used for the design of tunnels and culverts (e.g. Fabozzi et al. 2017; Argyroudis & Pitilakis 2012; Zurlo 2012; Hashash et al. 2001), this study comprises one of the few efforts to extend its application to the appraisal of underground monumental structures and is regarded as complimentary to the study of Kyriakides et. al. 2017, which focused on the 3D time-history numerical analysis under acceleration seismic excitation.
The geotechnical characteristics assumed for the site where the monument is located are based on the field investigation of Veldemiri et al. (2016) who performed a detailed seismic ground response analysis for the wider region of the city of Paphos. The latter included the implementation of boreholes at several locations and the execution of Cross-Hole and Down-Hole tests which enabled determining soil profiles and evaluating their dynamic properties. Results obtained from a certain borehole (A13) at the vicinity of the monument, indicate that the tomb was carved into a 10 m deep layer of calcarenitic sedimentary

rock, having a shear wave velocity of 500 to 650 m/s. Underneath the rock layer, clayey silt deposits that extend up to a depth of 140 m exist. The shear wave velocity of these soils increases progressively from 250 to 560 m/s. According to Veldemiri et al. (2016) the presence of calcarenite rock above considerably less stiff layers of soil is a particular characteristic of the specific area examined and can affect the seismic performance of structures. The assumed rock-soil layering and shear wave velocity profile are shown in Figure 3.

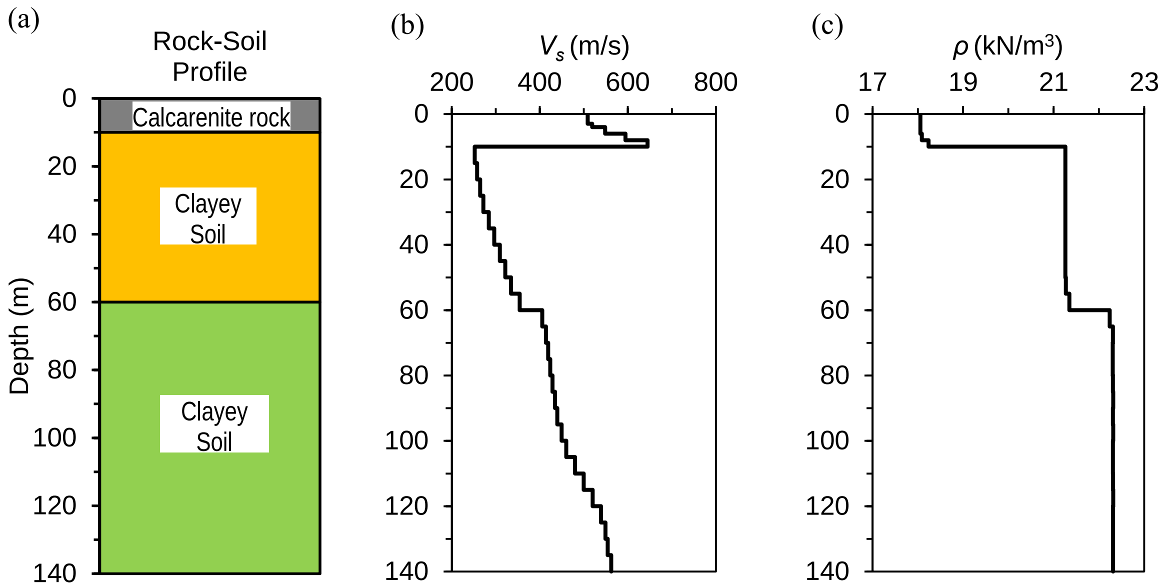

Figure 3. Assumed profile of rock-soil layers (a) and corresponding variations of shear wave velocity (b) and unit weight (c) based on the data reported in (Veldemiri et al. 2016).

The underground tomb monument was simulated in 2D using the FE code Abaqus/CAE (Simulia Corp. 2009). A plane strain model representing a longitudinal cross-section of the tomb and horizontally layered rock and soil strata was developed. The lateral extent of the calculation domain was set as 180 m, in order to ensure that the distance of each side from the central axis of the tomb is at least equal to three times its total cross-sectional width (i.e. 30 m), so as to minimize boundary effects (Argyroudis & Pitilakis 2012). Since the monument was entirely hewn out of the rock, the perimeter of the tomb's modelled section was connected to the surrounding rock and soil layers via common nodes. The typical plane strain thickness was set to 1 m for all regions of the model, except of the two parts representing the atrium pillars where a 0.3 m thickness was defined in accordance to the geometrical characteristics of the monument. The FE mesh consisted of 15091 4-noded bilinear quadrilateral elements with reduced integration and hourglass control (CPE4R), resulting to a total of 31338 degrees of freedom (Figure 4). The maximum size of the elements' length at the regions of the model representing the soil layers was set as 5 m. A denser mesh composed of elements with side lengths ranging from 0.1 to 0.25 m was assigned at the tomb's area. Vertical displacement of the nodes along the two sides of the model was constrained ($u_y = 0$), while both translational degrees of freedom at the bottom of the mesh were fixed ($u_x = u_y = 0$).

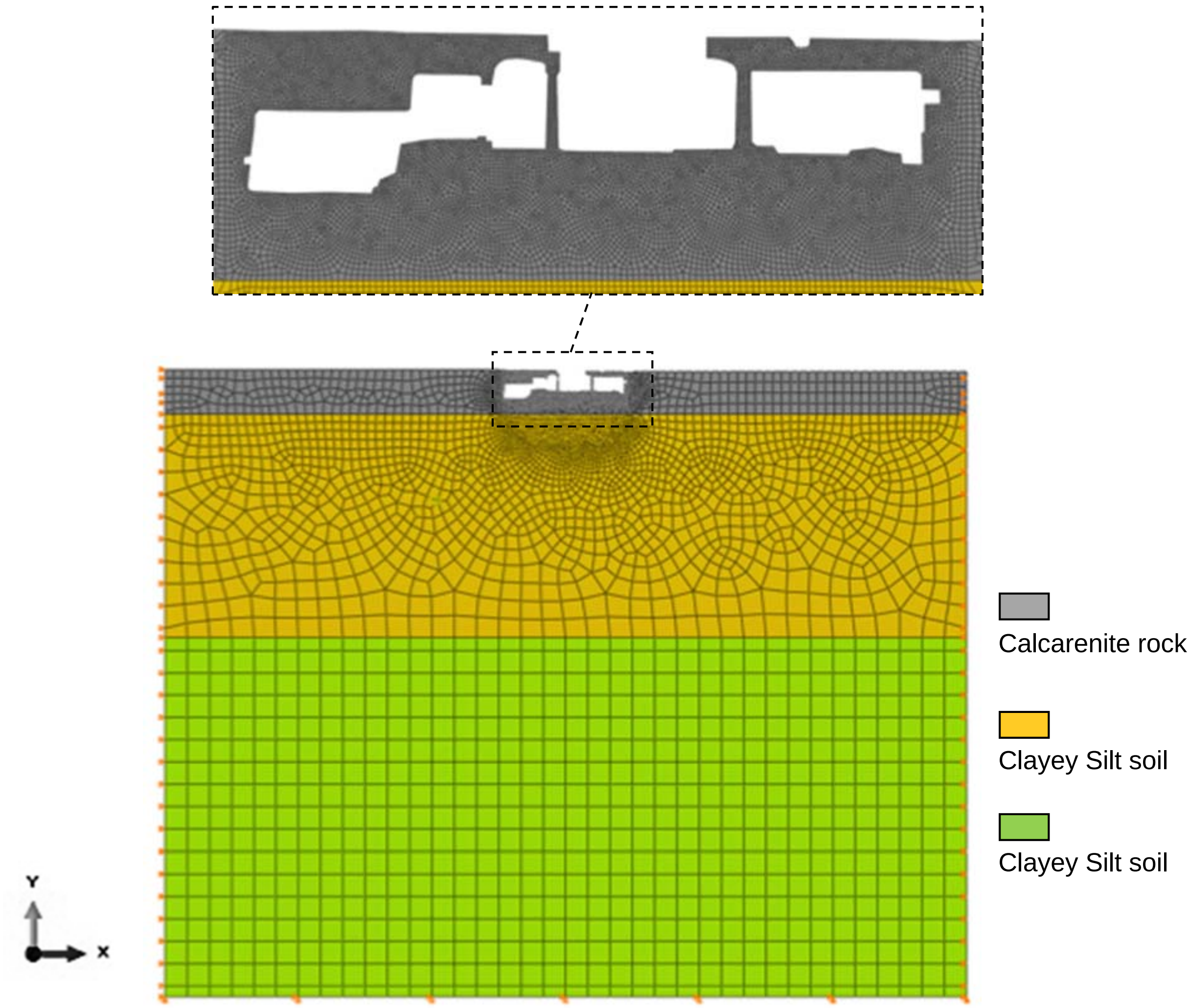

Figure 4. Plane strain FE model developed in Abaqus/CAE for examining the seismic response of the underground monument and mesh at the calculation domain corresponding to the tomb's cross-section.

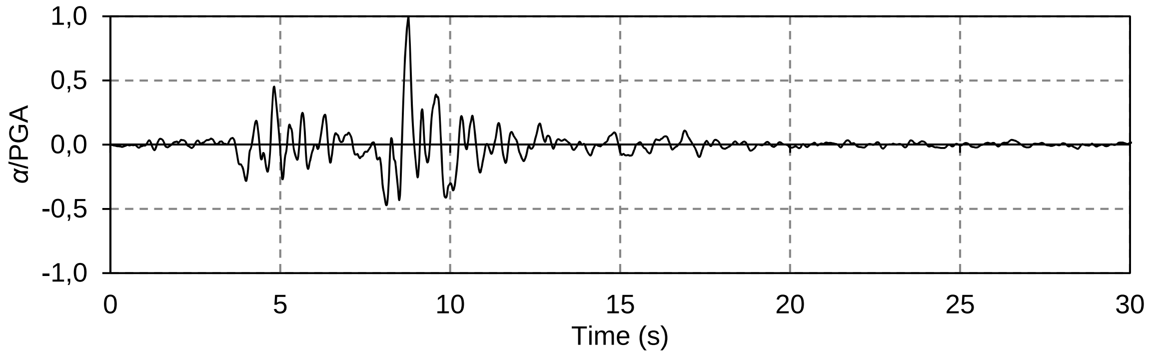

Figure 4. Accelerogram of the 1978 Thessaloniki earthquake used in the seismic analysis of the tomb monument.

The seismic input motion used for the analysis of the tomb is based on a record of the 1978 Thessaloniki earthquake (Figure 5). The accelerogram was scaled to a Peak Ground Acceleration (PGA) of 0.25g, which corresponds to the design value prescribed in the Cyprus National Annex to Eurocode 8 for the Paphos region. The quasi-static seismic ground displacements resulting from the action of the selected earthquake motion were computed following the 1D EQL approach by assuming an equivalent linear elastic soil behavior, using the code EERA (Bardet et al. 2000). The variations of the calcarenite rock's and clayey silt soil's shear moduli G/G_{max} and damping ratios D with respect to the shear strain level γ were defined according to relevant data from the literature (Vinale 1988; Seed & Sun 1989; Idriss 1990) (Figure 6). For carrying out displacement calculations, the rock-soil profile was discretized into a total of 31 layers, each with a thickness of 1 to 5 m. In the iterative procedure, the ratio between the effective and maximum shear strain was taken as 0.65. Cumulative displacements at different depths were estimated as a function of the computed peak shear strains. The computed profiles of peak shear strain, cumulative displacement and mobilized value of shear stiffness are shown in Figure 7.

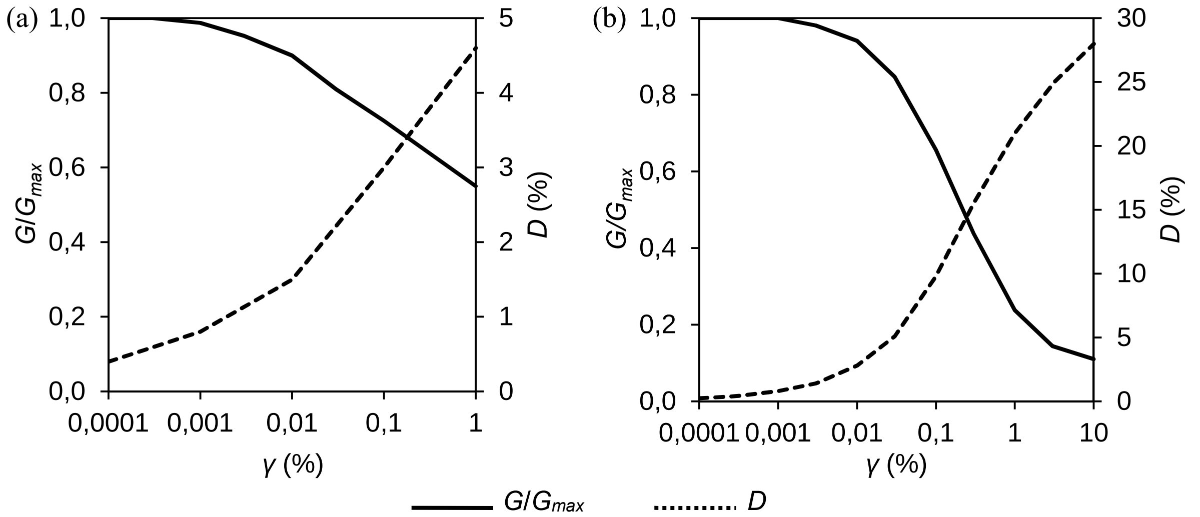

Figure 6. Shear modulus reduction (G/G_{max}) and variation of damping ratio (D) with shear strain (γ) assumed for the calcarenite rock (a) and the clayey silt soil (b).

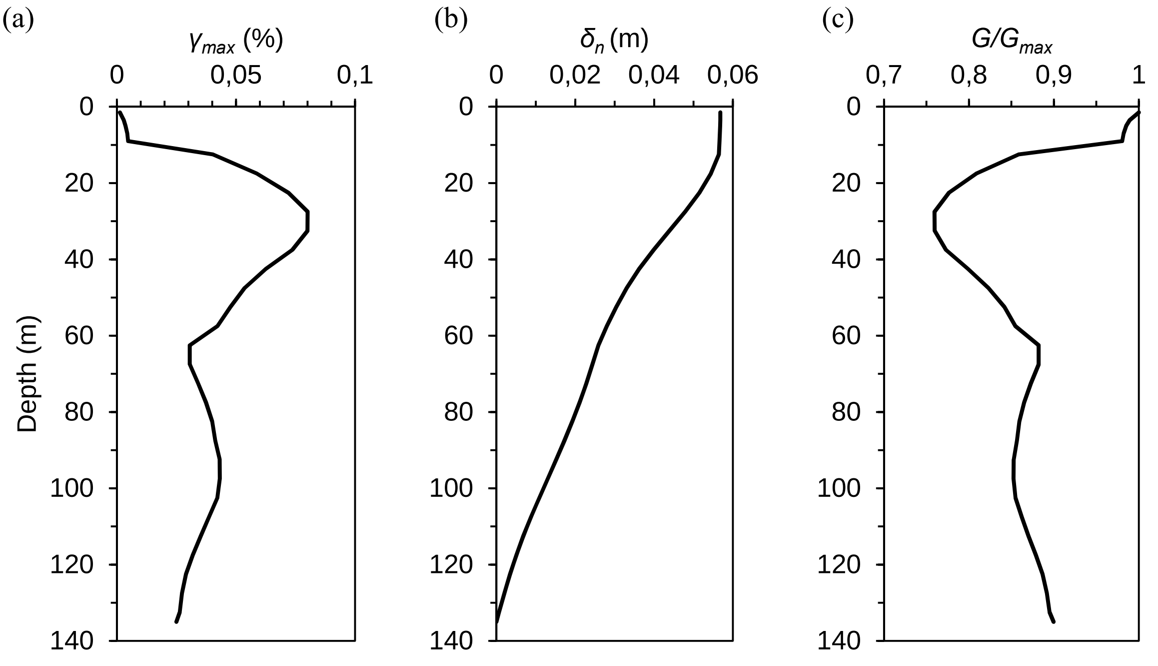

Figure 7. Results of 1D ground response analysis with EERA: variation of peak shear strain (a), cumulative displacement (b) and mobilized value of normalized shear stiffness (c) with respect to depth.

The outcomes of the 1D ground response analysis were also used to evaluate the moduli of elasticity that were assigned to the FE model for the simulation of the rock and soil. Both materials were hereby modeled as linearly elastic. The modulus of elasticity (E) at each depth level was defined in accordance to the variation of the equivalent shear modulus (G) computed from the free-field analysis (Figure 7c) as:

$$E = 2 \cdot G \cdot (1+v) \quad (1)$$

In the above equation v is the Poisson ratio; assumed to be constant and equal to 0.2 and 0.3 for the calcarenite rock and clayey silt soil, respectively.
FE numerical analysis was completed in two consecutive steps using a general static procedure with a full Newton solution technique. At the first step, a gravitational load was imposed at all parts of the model in order to simulate the initial static conditions of the problem. Subsequently, the calculated profile of peak horizontal displacements corresponding to the free-field ground response under the scaled accelerogram was applied to the side boundaries of the FE model.

4.2 Results of FE analysis

The outcomes of the FE analysis are presented in Figure 8 which shows the deformed mesh shape of the tomb's simulated cross-section along with the computed distributions of displacements in the *x* direction and of maximum principal tensile stresses.
According to the estimated displacement magnitudes, in the event of an earthquake generating a PGA of 0.25g, the columns supporting the tomb's atrium are expected to sustain a lateral drift in the region of 0.4%. Based on the provisions of FEMA 356, masonry piers subjected to in-plane loads have a nominal yielding drift of 0.1%, while at drifts ≥ 0.3% significant damage develops and at drift levels exceeding 0.4% the collapse prevention limit state is reached. This suggests that the stone columns can suffer from extensive cracking due to seismic action, which may even jeopardize their structural stability. Bearing in mind that most of the monument's columns are monolithic (i.e. entirely hewn out of the bedrock) and do not incorporate any joints allowing for slippage or rocking motion during dynamic excitations, it can be argued that these members may exhibit brittle behavior characterized by sudden tensile or shear failure.

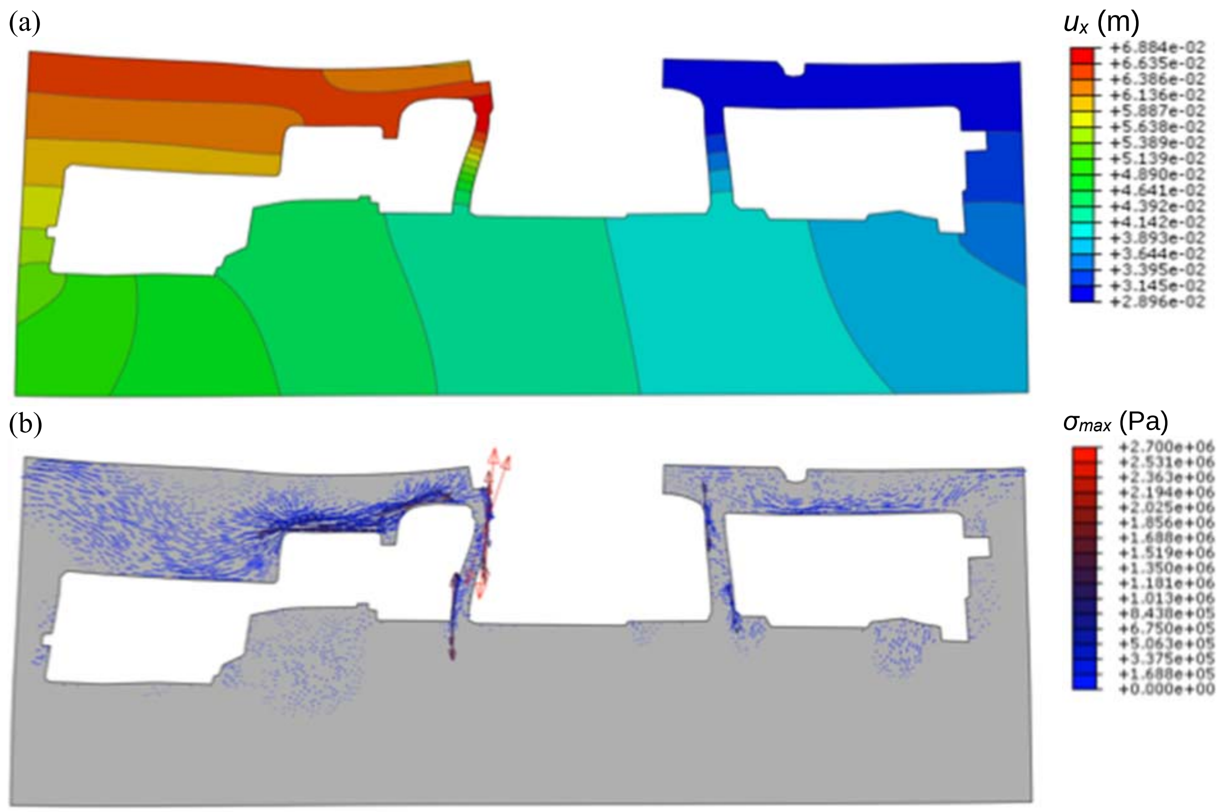

Figure 8. Deformed mesh shapes (displacements scaled up 25 times) of the tomb showing a contour distribution of displacements in the *x* direction (a) and a vector distribution of principal tensile stress (b).

The development of seismic damage at the column sections is further implied by the computed stress

distribution. The analysis shows the generation of tensile stresses > 1 MPa at the base and upper part of these elements. Significant concentrations of analogously high tensile stresses occur along the chamber section, at the eastern part of the tomb. A laboratory investigation carried out by (Modestou et al. 2016) concluded that local carbonate rocks have rather high porosity and relatively low tensile strength that can range from 1 to 4 MPa, depending on their mineralogical composition. Considering that the rock composing the members of the monument is exposed to the elements and has been affected by long-term weathering which has reduced its mechanical properties, it is rather safe to assume that cracking will develop at areas where tensile stresses between 1 and 3 MPa occur.
Indeed, the predicted damage distribution is, to a certain degree, verified by the crack pattern observed at the actual monument. A number of columns at the tomb's atrium exhibit fracturing at their base or incorporate cracks which extend throughout their height (Figure 9a). In addition, fissures are noted at both the exterior and interior of the chamber compartment (Figure 9b and c), at approximately the same areas where the analysis predicts the development of tensile stresses > 1 MPa. Correlation between the numerical results and the physical damage observed at the tomb indicate that cracking/fissuring was possibly caused by past seismic activity.

(a) (b) (c)

Figure 9. Pilasters and columns at the atrium of the tomb that exhibit cracking and fracturing at the base (a) and fissures at the exterior (b) and interior (c) of the chamber compartment.

5. CONCLUSIONS

A field survey involving the use of advanced TLS and GPR methods was undertaken to examine the condition and analyze the pathology of an ancient monumental tomb complex located in Paphos, Cyprus. Processing of the data obtained from the in situ investigation enabled the formulation of a 3D digital model that accurately captures the geometry of the site. Detailed mapping of the cracks present on the surface of the tomb's architectural members was also performed. Furthermore, the study resulted to valuable information regarding the occurrence of anomalies within the mass of the structure's stone elements. These provide indications concerning the development/propagation of cracks and the existence of discontinuities within the rock material.
Using relevant data from the literature a seismic analysis of a specific tomb structure was carried out. For this purpose, a 2D plane strain model was developed and was subjected to linear static loading by imposing the free-field cumulative displacements generated by an earthquake motion scaled to the design PGA of the particular area under study. The analysis predicted the development of high tensile stresses at certain areas of the tomb, implying the occurrence of cracking damage. Interestingly enough, these areas practically coincide with sections of the actual monument where physical damage is observed. Further research is in progress to evaluate all aspects of the monument's seismic behavior.

6. ACKNOWLEDGMENTS

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From space to ground. Digital techniques for the investigation of monuments and sites

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Abstract

The scope of this work is to present an integrated methodological multi-scale and multi-temporal approach for the study of ancient monuments in their environmental context. The presented work showcases the interdisciplinary research experience gained during the last years by the Remote Sensing and Geo-Environment Lab (ERATOSTHENES Research Centre) of the Cyprus University of Technology. The developed capabilities of the Eratosthenes Research Centre derived from the successful implementation of various national and European research projects within the wider area of architectural heritage study and protection. In this framework geospatial tools, earth observation and in situ monitoring and measurements were merged and further investigated. The case study concerns Paphos town in Cyprus and particularly the archaeological site of Nea Paphos and the Hellenistic necropolis "Tombs of the Kings", a UNESCO World Heritage Site.

The study encompasses a variety of technological tools to approach the area of interest, moving from a landscape level (macro-scale) to isolated monument scale (micro-scale). For the macro-scale approach novel earth observation and aerial image (semi-macro scale) processing techniques have been employed, while in a micro-scale level the study extents from the geometric documentation of the tombs to the image processing mapping surface weathering features, as well as seismic performance of single monuments. The overall results demonstrate that such geospatial data linked to the individual characteristics of each monument can assist towards the implementation of various directives and conventions, while offering an integrate understanding of the monuments state of preservation, not seen as an isolated unit, but as part of its natural and anthropogenic environment, inevitably affecting its viability in time and place.

Keywords

Architectural heritage; remote sensing; aerial images; Paphos; monitoring

I. INTRODUCTION

The paper aims to present a holistic framework based on various digital technologies for the investigation of monuments in different scales and levels. In the last years, research activities and projects have given the opportunity to implement different methodologies to an UNESCO World Heritage Site, in Cyprus (see section 2), targeting towards the further investigation and multi-temporal monitoring of the site as well as hazard detection and mapping. The overall results and their synthesis are here presented, targeting to demonstrate and highlight the potentialities offered by integrating space and ground technologies, for other important monuments and sites on the island and beyond.

Monuments and sites are systematically threatened by various anthropogenic and natural hazards such as climate change, urban sprawl, seismic activity, soil erosion etc. The complexity of the archaeological context itself, as well as the various types of occurring threats, makes the overall approach for preservation and protection of cultural heritage very complicated. To overcome several barriers, economic tightness included, innovative technologies and methods are needed to be implemented for acquiring reliable results in various scales: from a territorial level to the level of the monument itself. Several examples are found in the literature related to the use of non-contact and non-destructive techniques for monitoring cultural heritage sites [1]. In [2], earth observation was applied to detect illegal looting actions taken place in the historical city of Uruk, while in [3] earth observation was applied to map and monitor changes in the type and extent of land cover/use and habitat classes, which can be related to human pressures in cultural heritage sites over time.

II. CASE STUDY AREA

The area under investigation is located in the western part of Cyprus. The “Nea Paphos” archaeological site along with the “Tombs of the Kings” are listed as UNESCO World Heritage monuments since 1980. Both sites are found near the coastline on the western part of the modern city of Paphos (Fig. 1). The sites are considered amongst the most attractive sites for tourism in the island, with more than 200,000 visitors per year. The protected sites cover more than 1 square kilometer, a matter that implies the necessity of a landscape and environmental monitoring.

Fig. 1. Area of interest: “Nea Paphos” and “Tombs of the Kings” archaeological sites

III. Methodology

The methodology followed suggests a non-contact monitoring and investigation of the sites, based on a multi-level approach as shown in Fig. 2. In the macro-scale level earth observation space sensors have been used to map the various threats occurred through time (from 1980s' until today). Satellite data included low, medium and high resolution multi-spectral images, such as MODIS and Landsat series (Landsat 5 TM, Landsat 7 ETM+ and Landsat 8 LDCM sensors), used to examine and map potential hazards (such as urban sprawl, air pollution, landslides, fires, soil erosion) of the wider area of Paphos town. Technically, the images received the necessary pre-processing operations (i.e. geometric and radiometric corrections). Thereafter, various post-processing image analyses occurred separately for each hazardous parameter under investigation [4]. An overall hazard map of the area produced based upon the Analytical Hierarchy Process (AHP). The results evidenced critical areas of Paphos Region marked as high-risk zones.

Shifting to a middle range observation level, archive and recent aerial photographs (up to 20 cm spatial resolution), provided by the Department of Land and Surveys of Cyprus, have been processed and analyzed. In addition, archived Royal Air Force (RAF) photographs capturing the area under investigation during the 1940s, have been merged with modern orthophotos, aiding the detection of old traces and crop / soil marks in the area. Such marks have been lost during the last decades mainly due to soil erosion of the archaeological sites, and can be retrieved only through image enhancement.

Changing scale and moving to ground level, the research focused on the terrestrial investigation of a single monument (tomb). To this end, a geometric documentation of the monument has been carried out and various scenarios for its seismic performance were applied. In addition, digital image processing of rectified images of the monument's facades to map and quantify surface deterioration have been produced.

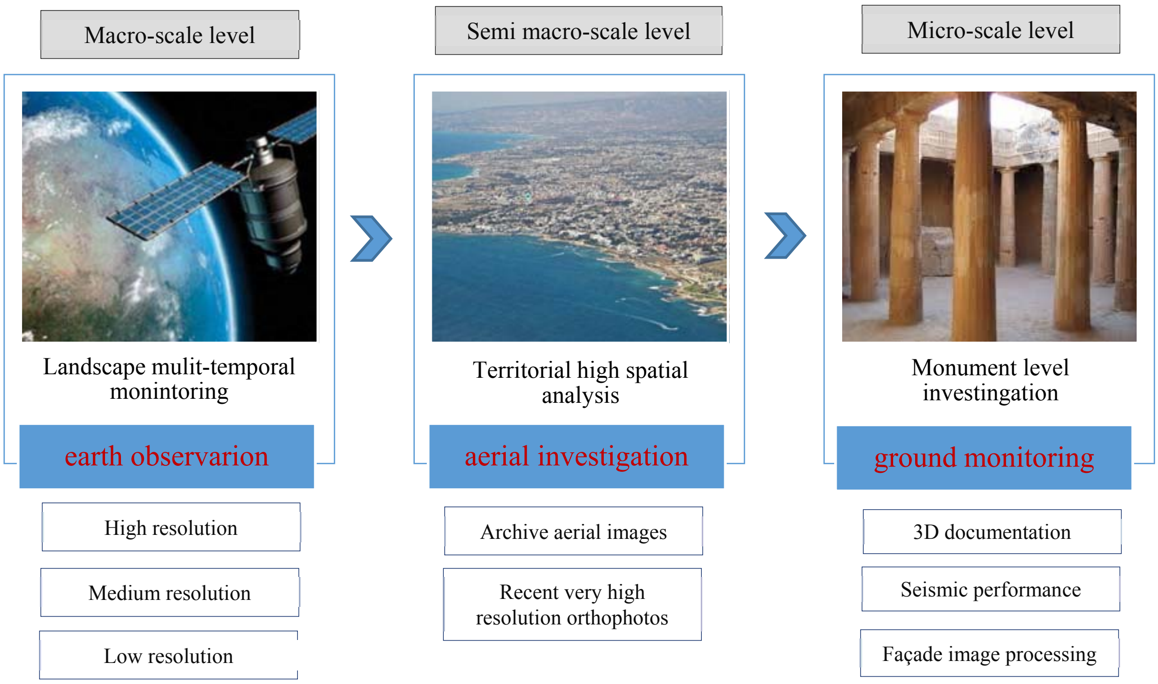
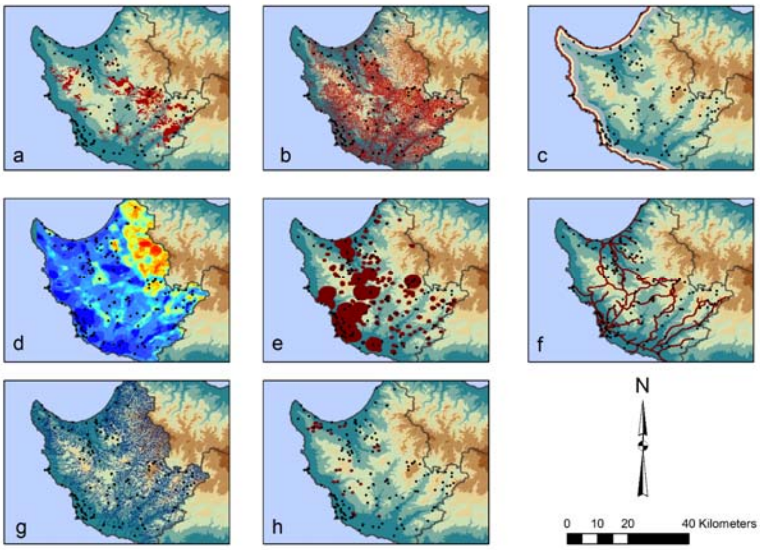


Fig. 2. Multi-level approach for monintoring monuments and sites

IV. Results

A. *Macro-scale level*

In the macro-scale level, the potential hazards of the wider area of Paphos were defined and evaluated using satellite multi-temporal datasets. The hazards were divided into two main categories: (a) natural (landslides; erosion; salinity and neotectonic activity) and (b) anthropogenic (urban sprawl; modern road network; drainage network and fires) [4]. Low resolution space data like the Moderate Resolution Imaging Spectroradiometer (MODIS) Terra and Aqua platforms and Defense Meteorological Satellite Program (DMSP) - Operational Linescan System (OLS), medium resolution images from Landsat and ASTER sensors, as well as high resolution data from QuickBird have been processed separately. Results from the analysis of the low-resolution MODIS Terra and Aqua products regarding the Aerosol Optical Thickness (AOT) over the area of interest for the entire year of 2012 have shown the AOT fluctuations over the seasons [5]. AOT is linked to the air pollution, and therefore insights regarding the impact of the pollutants to the standing monuments can be investigated. In a similar way, all the above mentioned hazards have been mapped for this area of Paphos town and region, using a Geographical Information System (GIS) (Fig. 3).



(a)

Fig. 3. Map indicating anthropogenic and natural hazards over Paphos District as follow: (a) Landsides map: very high hazard and high hazard areas are indicated with red; (b) Erosion map: areas where the soil loss is greater than the mean value soil loss of the whole district are indicated with red ; (c) Salinity map: areas closesly to the sea are indicated with red; (d) Tectonic activity: high and very high hazard area are indicated with red; (e) Urban expansion; (f) Road network proximity (250 m); (g) Drainage network (50 meter buffer zone) and (h) Fires map observed during the period 2010-2013 (see more details in [4]).

The overall results, generated hazard maps for each type of threat which was then grouped together following the AHP methodology [4]. These results were then further improved [6], based on the clustering of the monuments prior to the AHP evaluation. The various archaeological sites under investigation (including those mentioned in this paper) have been grouped into five main categories based on their characteristics, susceptible to related risks:

Class 1: Monuments/sites located in low elevations, far from the coastline, within active tectonic regions; close to main road network and urban areas. Limited threats from soil erosion, but within areas with high possibility of fires.

Class 2: Monuments/sites located on hilly areas, far from the coastline, within active tectonic regions; away from main road network and urban areas. Limited threats from soil erosion, but within areas with high possibility of fires.

Class 3: Monuments/sites located in very high elevations, far from the coastline, away from active tectonic regions; close to main road network and urban areas. Threats from soil erosion and limited threats from fires.

Class 4: Monuments/sites located nearby the coastline, in low altitude and in the vicinity of urban areas and main road network. Limited threats from soil erosion and limited threats from fires. Within active tectonic regions.

Class 5: Monuments/sites located in medium elevations, far from the coastline, within active tectonic regions; close to main road network and urban areas. Threats from soil erosion and limited threats from fires.

Paphos town with the ancient city and the necropolis 'Tombs of the Kings' enter in Class 4. The overall hazard map produced following the AHP methodology is shown in Fig. 4, evidencing that the area under investigation is marked as of "very high hazard".

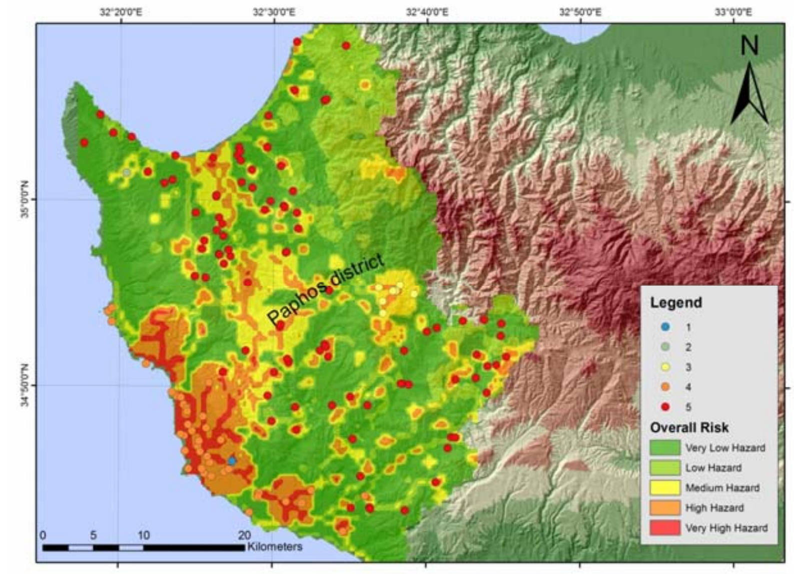


Fig. 4. Overall risk hazard map for the Paphos district, based on the clustering of the sites [6].

B. Semi macro-scale level

Beyond the known and standing monuments, these areas are also rich in terms of buried and still unexcavated archaeological remains (Fig. 5). To detect and map potential traces of the remains, archive and recent aerial photographs have been used. Towards this end, identification of potential crop and soil marks [7], which are considered as a proxy for buried archaeological remains was studied. Based on pan-sharpening techniques these marks could be enhanced and identified from recent orthophotos (see [7]). Several marks were also identified after photo-interpretation and *in situ* inspections, using Global Navigation Satellite Systems (GNSS). The rich context found at the archive aerial images indicates once again the important aspects of the cultural heritage that these sites are holding, which however can be threaten from various hazards, in this particular case, the soil erosion.

Fig. 5. High Pass Filter (HPF) transformation of archive aerial image (1945) and a more recent one (2014) over the archaeological site of Nea Paphos [9].

C. Micro-scale level

The micro-scale survey concerned a single monument, specifically Tomb 4 of the “Tombs’ of the Kings” ancient cemetery. The geometric documentation was the backbone for all following digital and numerical elaborations accomplished in the micro-scale level. Various close-range techniques for the documentation of the site and its monuments have been carried out in recent years, mainly for research purposes. Terrestrial laser scanner (Fig. 6, left) and close-range photogrammetry have been processed in selected monuments to capture their geometry, decipher their architecture, as well as for future preservation and digital reconstruction research. Geometric documentation of Tomb 4, along with *in situ* inspection and mapping of the cracks observed, permitted its structural investigation. To correlate the monument’s structural state of preservation to ancient or more recent earthquakes, a numerical finite element model of the structural resisting system of the tomb (geometry in a 3D space) including mapped wall crack pattern and the material properties was drawn and its seismic response to various time-history loading scenarios was simulated [8]. The overall results leaded to better understanding of the structure’s behaviour (Fig. 6, right), while permitted speculation on other geo-environmental parameters that possibly caused material deterioration throughout the centuries. It was also concluded that frequent moderate seismic activity in the Eastern Mediterranean region increases the structural vulnerability of such monuments through increased cracking of the stone wall material especially at the base level, and may lead to catastrophic collapse in case of low probability larger seismic events, with a recurrence rate greater than 2000 years. Therefore, the systematic monitoring, maintenance and retrofit of monuments accessible to the public should be amongst the general strategic priorities in a local level.

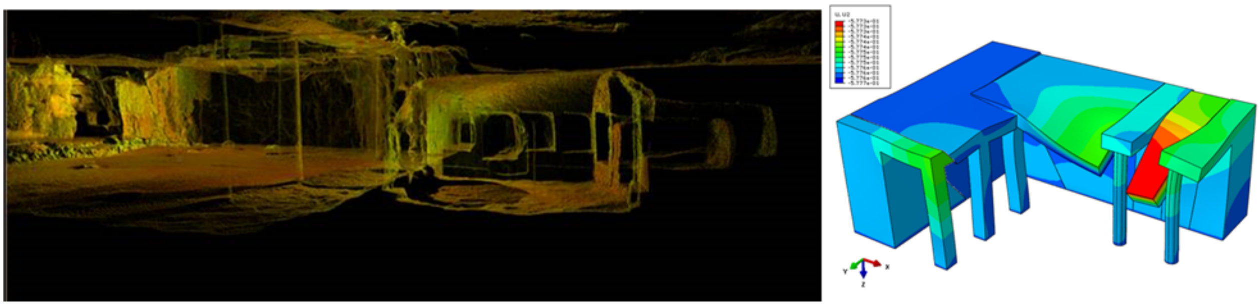


Fig. 6. Left: 3D documentation (points cloud) of one of the necropolis atrium tombs. Right: Distribution of maximum principal stresses [see more in 8].

A final application of the micro-scale analyses involved rectified Red-Green-Blue (RGB) photographs of the monuments' facades, using image classification techniques (Fig. 7). The orthophotos have been introduced, analyzed and processed using the ERDAS Imagine software. Supervised classification was applied using specific areas of the images as "training spots". In addition, a series of processing parameters, such as threshold filtering and image enhancement, have been implemented, resulting an overall mapping of the surface state of preservation of the tomb. Semi-automatic quantification of the individual weathering conditions on a larger scale on the monuments vertical walls was the overall result of the Digital Image Processing.

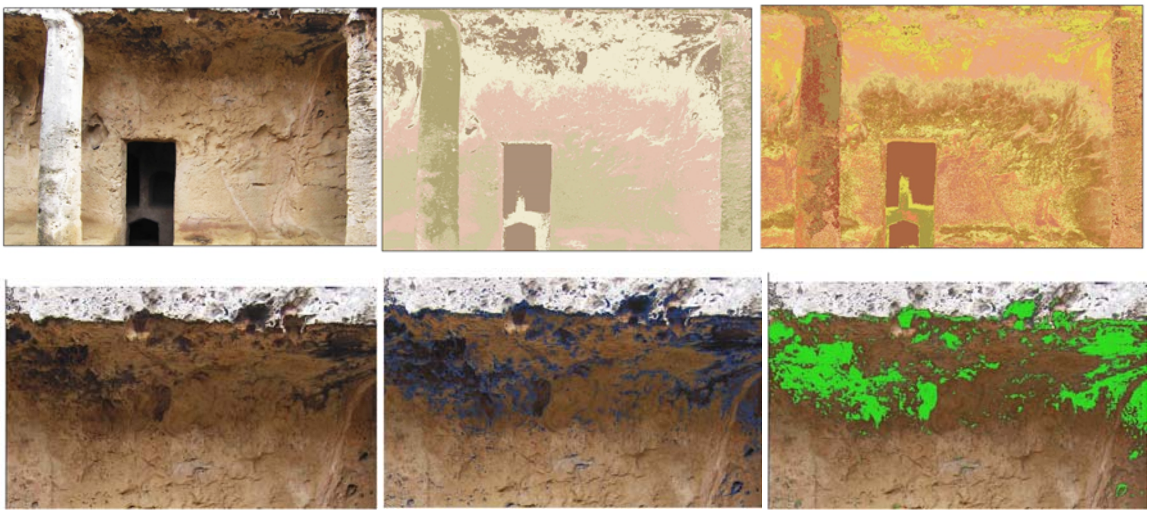


Fig. 7. Preliminary results of the Digital Image Processing. Above: Overall of the eastern internal wall of Tomb no 4, seen form the atrium. Below: Detail of the same wall highlighting voids or their contours.

V. Conclusions

Natural and anthropogenic hazards on monuments are directly or indirectly connected to a series of parameters to be taken into consideration, tangling a considerable number of disciplines involved and means to be employed. The present study displayed a methodological approach for the investigation of ancient structures, their sites and environment, shifting from space to terrestrial level, but most importantly operating in a non-contact, non-destructive domain.

The overall results and the integration of the data obtained from the different types of analyses, provided a unified visibility of the site, single monuments included. This approach consists of an operational methodological framework for archaeological sites and their surroundings strategic monitoring and protection, considering not only the expected natural deterioration of monuments, but also eventual risks provoked by the changing environmental context of the sites due to modern life's needs and evolution [9]. Therefore, directly linked to what, we may say, the World Heritage Convention since the beginning clearly sets as "… the cultural heritage and the natural heritage are increasingly threatened with destruction not only by the traditional causes of decay, but also by changing social and economic conditions which aggravate the situation with even more formidable phenomena of damage or destruction".

Even though outdated, still in a timely manner is here recalled the suggestion of the Convention for the Protection of the Architectural Heritage of Europe [10], which, in terms of European co-ordination of conservation policies, stressed the investigation of "the possibilities afforded by new technologies for identifying and recording the architectural heritage and combating the deterioration of materials as well as in the fields of scientific research, restoration work and methods of managing and promoting the heritage" Article 17(3)]. Indeed, the possibilities provided by innovative technologies currently in use offer great potential for systematic observation of cultural heritage sites in different levels and most importantly these technologies can readily be used due to a variety of free access data, a crucial advancement particularly in the cases of emergency. Towards this direction the INSPIRE European legislation foresees the creation of an infrastructure for sharing spatial data information. Amongst its 34 spatial data themes, protected sites and natural risk zones are included, offer readily support for the implementation and monitoring of environmental policies, reporting and easy access of environmental information for the public, as well as for other policy areas (e.g. disaster management, Copernicus).

On 18^{th} of June 2003 UNESCO and the European Space Agency (ESA) signed an agreement to encourage earth observation sensors for monitoring cultural and natural World Heritage sites. The signing of the Agreement officially launched the 'Open Initiative on the Use of Space Technologies to Support the World Heritage' convention [10]. This agreement was emanated from the Convention Concerning the Protection of the World Cultural and Natural Heritage to develop scientific and technical studies and research to work out operating methods capable of counteracting various dangers that threaten cultural or natural heritage. The convention also argues the necessary measures needed to be taken in legal, scientific, technical, administrative and financial aspect for the identification, protection, conservation, presentation and rehabilitation of this heritage (articles 5c and 5d). The Open Initiative "*aims to develop a framework of co-operation, open to space agencies, research institutions, non-governmental organizations (NGOs) and the private sector in order to assist developing countries, though, space technologies to improve their natural and cultural conservation activities*". On 8 July 2016 Cyprus became the 11th country to sign the European Cooperating State Agreement, strengthening its relations with ESA also towards this direction. Within this framework, systematic efforts have been made by the authors in the last years in order to exploit the capabilities of earth observation as well as to downscale the level of work in a monument scale.

Future work foresees more terrestrial analysis at a monument level, involving the ground penetrating radar for structural investigation and possible failures, since past restoration works are not documented. This will trigger a more thorough structural analyses of single monuments and their performance, while the properties of building materials will be further examined.

ACKNOWLEDGMENT

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ΟΦΕΛΗ ΠΟΥ ΠΡΟΚΥΠΤΟΥΝ ΑΠΟ ΤΟ ΠΡΟΓΡΑΜΜΑ "ATHENA" HORIZON 2020 TWINNING ΣΤΟΝ ΤΟΜΕΑ ΤΗΣ ΠΟΛΙΤΙΣΤΙΚΗΣ ΚΛΗΡΟΝΟΜΙΑΣ ΜΕ ΤΗΝ ΧΡΗΣΗ ΤΗΣ ΤΗΛΕΠΙΣΚΟΠΗΣΗΣ

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ΛΕΞΕΙΣ ΚΛΕΙΔΙΑ: τηλεπισκόπηση, ερευνητικό πρόγραμμα ATHENA, πολιτιστική κληρονομιά, εκπαίδευση

ABSTRACT:

Ο σκοπός αυτής της εργασίας είναι η ανάδειξη του οφέλους που προκύπτει με την συμμετοχή και τον συντονισμό στο έργου «ATHENA» Horizon 2020 Twinning από το Εργαστήριο Τηλεπισκόπησης και Γεωπεριβάλλοντος του Τεχνολογικό Πανεπιστήμιο Κύπρου (Ερευνητικό Κέντρο Ερατοσθένης). Το έργο «ATHENA» στοχεύει στη δημιουργία ενός Κέντρου Αριστείας στον τομέα της Τηλεπισκόπησης για την Πολιτιστική Κληρονομιά μέσω της ανάπτυξης μιας βελτιωμένης βάσης γνώσεων και καινοτόμων μεθόδων. Το κέντρο αυτό θα δημιουργηθεί με βάση το υφιστάμενο Εργαστήριο Τηλεπισκόπησης και Γεωπεριβάλλοντος του Τεχνολογικού Πανεπιστημίου Κύπρου (CUT) σε συνεργασία με διεθνούς κύρους συνεργάτες, όπως το Ινστιτούτο Αρχαιολογικής και Αρχιτεκτονικής Κληρονομιάς του Εθνικού Συμβουλίου Έρευνας Ιταλίας (IBAM-CNR) και το Γερμανικό Αεροδιαστημικό Κέντρο (DLR). Στα πλαίσια του έργου «ATHENA», πραγματοποιούνται μαθήματα κατάρτισης, εργαστήρια και άλλες δραστηριότητες που στόχο έχουν τη δημιουργία ενός δικτύου υποστήριξης για τη συγκέντρωση γνώσεων και εμπειρίας σε τοπικό επίπεδο. Επιπρόσθετα, γίνεται εισαγωγή μεθοδολογιών τηλεπισκόπησης και χρησιμοποιούνται νέα συστήματα για την ανάπτυξη εφαρμογών για την πολιτιστική κληρονομιά. Με την χρήση της τηλεπισκόπησης επιτυγχάνεται η διατήρηση, η ανάλυση και η παρακολούθηση της πολιτιστικής κληρονομιάς καθώς και ο εντοπισμός νέων αρχαιολογικών χώρων.Τέλος, το έργο θα αναδείξει το Κέντρο διεθνώς, θα διευκολύνει μελλοντικές συνεργασίες μέσω ανταλλαγής προσωπικού μεταξύ των εταίρων και θα αυξήσει την συμμετοχή σε διεθνείς συνέδρια..

1. ΕΙΣΑΓΩΓΗ

Κατά τις δύο τελευταίες δεκαετίες, έχουν επιτευχθεί ραγδαίες εξελίξεις σε τεχνολογίες που σχετίζονται με την τεκμηρίωση και χαρτογράφηση μνημείων και συνόλων, όπως η τηλεπισκόπηση και τα Γεωγραφικά Συστήματα Πληροφοριών (ΓΣΠ), διανοίγοντας - ανάμεσα στις πολλαπλές τους εφαρμογές- νέες δυνατότητες στην αρχαιολογική έρευνα, την αρχαιολογική ανάλυση και ορατότητα και γενικότερα στη διαχείριση πολιτισμικών μνημείων και χώρων.

Ως Τηλεπισκόπηση ορίζεται η επιστήμη της συλλογής, ανάλυσης και ερμηνείας πληροφοριών για ένα συγκεκριμένο στόχο, ώστε να εντοπιστούν, να μετρηθούν και να ποσοτικοποιηθούν οι ιδιότητές του μέσα από τις αλληλεπιδράσεις της ηλεκτρομαγνητικής ακτινοβολίας, χωρίς τη μεσολάβηση καμίας άμεσης και φυσικής επαφής με τον υπό διερεύνηση στόχο. Ως εκ τούτου, διάφορες τεχνικές όπως είναι η δορυφορική τηλεπισκόπηση, η αεροφωτογράφιση, οι επίγειες γεωφυσικές διασκοπήσεις, τα υπερηχητικά όργανα, καθώς και η τρισδιάστατη σάρωση αντικειμένων, αποτελούν επιστημονικά πεδία της Τηλεπισκόπηση.

Οι βασικές αρχές του επιστημονικού τομέα της Τηλεπισκόπησης πηγάζουν μέσα από τις ιδιότητες της ηλεκτρομαγνητικής ακτινοβολίας. Όλα τα αντικείμενα, εξαιρουμένων αυτών που βρίσκονται στο απόλυτο μηδέν (0 K/ -272,2o C), εκπέμπουν ηλεκτρομαγνητική ακτινοβολία. Ανάμεσα στις διάφορες μορφές ηλεκτρομαγνητικής ενέργειας περιλαμβάνεται το ορατό φως, τα ραδιοκύματα, η θερμότητα, η υπεριώδης ακτινοβολία, οι ακτίνες Χ κ.ά. Μάλιστα οι μορφές ακτινοβολίας πέρα από το ορατό φάσμα απαιτούν ιδιαίτερη προσοχή από τους ερευνητές, αφού κατά κανόνα συμπεριφέρονται «ξένα» σε σχέση με την καθημερινή επαφή και εμπειρία του ανθρώπου με το ορατό φάσμα (Campbell, 2002).

2. ΙΣΤΟΡΙΚΗ ΑΝΑΔΡΟΜΗ

Οι απαρχές της τηλεπισκόπησης ανάγονται στο 1840, περίοδο κατά την οποία λήφθηκαν οι πρώτες αεροφωτογραφίες από αερόστατα, ενώ η πρώτη γνωστή καταγραφή καταστροφής με τη βοήθεια της τηλεπισκόπησης πραγματοποιήθηκε το 1906 μετά από σεισμό στο San Francisco. Το 1909 λήφθηκαν και οι πρώτες φωτογραφίες από αεροπλάνα, ενώ η πιο καινοτόμος, ίσως, πλατφόρμα που χρησιμοποιήθηκε στην Ευρώπη στα τέλη του προηγούμενου αιώνα ήταν τα περιστέρια. Η αεροφωτογραφία αποτέλεσε ένα πολύτιμο εργαλείο παρακολούθησης κατά τη διάρκεια του Πρώτου Παγκοσμίου Πολέμου, ενώ τέθηκε σε πλήρη εφαρμογή κατά τη διάρκεια του Δευτέρου Παγκοσμίου Πολέμου. Το 1957 εγκαταστάθηκαν στον Sputnik οι πρώτες φωτογραφικές κάμερες σε διαστημόπλοια, ενώ στις αρχές του 1960, τοποθετήθηκαν αισθητήρες στους πρώτους μετεωρολογικούς δορυφόρους παρέχοντας ασπρόμαυρες εικόνες της Γης. Η ιδέα της χρησιμοποίησης της τηλεπισκόπησης για τη συλλογή πληροφοριών σχετικών με την επιφάνεια της Γης σε συστηματική βάση, ωρίμασε τη δεκαετία του 1970, περίοδος κατά την οποία διάφοροι αισθητήρες τοποθετήθηκαν στον Skylab και αργότερα στα διαστημικά λεωφορεία.

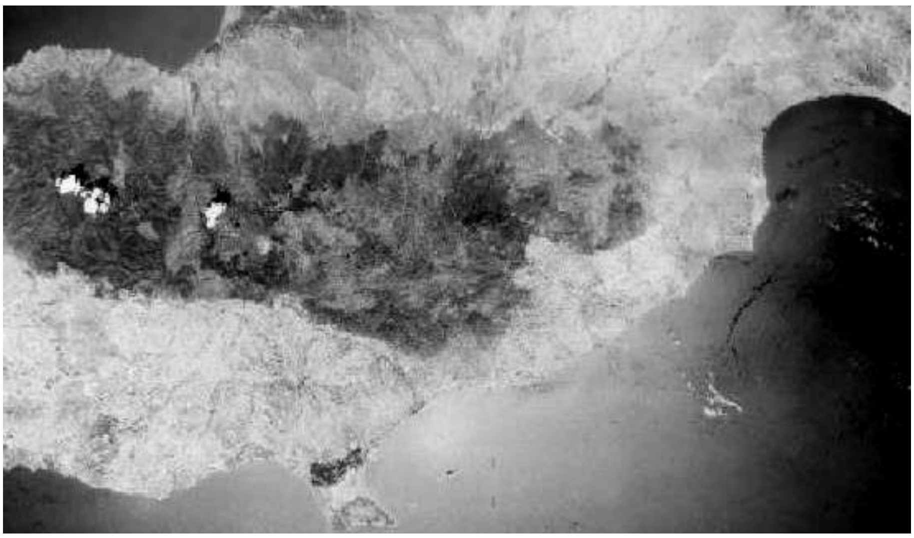
Η δεκαετία του 1970 σηματοδοτείται από το διαστημικό πρόγραμμα της NASA, που στόχο είχε την παρατήρηση της Γης. Ο πρώτος δορυφόρος της σειράς Landsat τέθηκε σε τροχιά το 1972 από το Υπουργείο Εσωτερικών των ΗΠΑ και τη NASA με το όνομα ERTS (Earth Resources Technology Satellites). Από το 1972 μέχρι το 1930, η πρώτη γενιά των δορυφόρων Landsat 1, 2 και 3 κινούνταν πάνω από τη γη σε ήλιο-σύγχρονες τροχιές. Η δεύτερη γενεά δορυφόρων Landsat 4 και 5 είχε τοποθετηθεί σε τροχιές παρόμοιες με τις προηγούμενες. Οι Landsat 4, 5 και 7 έχουν περίοδο περιστροφής 99 λεπτά σε ύψος πτήσης 705 χιλιόμετρα και επαναληπτικότητα 16 ημερών, σε αντίθεση με τους Landsat 1, 2 και 3 που είχαν επαναληπτικότητα 18 ημερών. Οι χρονοσειρές δορυφορικών εικόνων που μπορεί να παρέχει ο Landsat αποτελούν ισχυρό εργαλείο για διάφορες έρευνες, εφόσον παρέχει περισσότερες πληροφορίες από αυτές που μπορούν να εξαχθούν μέσα από αναλύσεις μίας ή δύο δορυφορικών εικόνων διαφορετικών ημερομηνιών. Τα τελευταία χρόνια τα δεδομένα Landsat συμπεριλαμβανομένων των Multispectral Satellite Sensor (MSS), Thematic Mapper (TM) και Echanced Thematic Mapper (ETM), είναι διαθέσιμα προς όλους τους χρήστες μέσω του United States Geological Survey (USGS) χωρίς καμία οικονομική επιβάρυνση. Από το1972 και εξής έχει επιτευχθεί η χωρική κάλυψη του μεγαλύτερου τμήματος της γης, από μία σειρά επτά συνολικά δορυφόρους, με πιο πρόσφατο τον Landsat 8, ο οποίος τέθηκε σε τροχιά στις 30 Μαΐου 2013 (Landsat Science).

Η δεκαετία του 1980 χαρακτηρίζεται από την ανάπτυξη των πολυφασματικών, θερμικών δεκτών, αλλά και των εικόνων ραντάρ. Στα τέλη της δεκαετίας του 1980 η Ινδία εκτοξεύει πολυφασματικούς δορυφόρους στο διάστημα. Παρόμοιας ανάλυσης δορυφόροι με τους Landsat αποτελούν και οι Ινδικοί IRS 1A,1B, 1C, 1D και IRS P2. Αν και έχουν χρησιμοποιηθεί για αρχαιολογικούς σκοπούς, όπως για παράδειγμα την αναγνώριση της μυθικής θέσης Dvaraka στην Ινδία ή για τον εντοπισμό θέσεων στην περιοχή Hampi, Ινδία, εντούτοις είναι φανερή η απουσία χρήσης τους στον ευρωπαϊκό χώρο.

Από τη δεκαετία του 1990 και μετά στο χώρο της Τηλεπισκόπησης κυριαρχούν πλέον τα ΓΣΠ, αλλά και νέα δορυφορικά συστήματα υψηλής χωρικής ευκρίνειας. Οι σύγχρονοι δορυφόροι Quickbird, IKONOS, WorldView και GeoEye παρέχουν σήμερα εικόνες με μεγάλη διακριτική ικανότητα, οι οποίες είναι διαθέσιμες και για αρχαιολογική έρευνα. Η ανάλυση των εικόνων μπορεί να φθάσει μέχρι και τα 0.5 m για το παγχρωματικό, ενώ στο υπέρυθρο φάσμα η ανάλυση είναι της τάξης των λίγων μέτρων.

Επιπρόσθετα, από το 2000 και εξής έχουν κάνει την εμφάνισή τους και οι δορυφορικοί υπερφασματικοί σαρωτές (π.χ. HYPERION), οι οποίοι μπορεί να είναι και αερομεταφερόμενοι (π.χ AIS, AVIRIS, CASI, MIVIS). Σε αντίθεση με τη συμβατική πολυφασματική τηλεπισκόπηση, η οποία βασίζεται στη χρήση περιορισμένου αριθμού καναλιών με μεγάλο εύρος φασματικής περιοχής, η υπερφασματική τηλεπισκόπηση βασίζεται στη χρήση και ανάλυση εκατοντάδων καναλιών πολύ μικρού εύρους φασματικής περιοχής (Agapiou et al., 2012, Alexakis et al., 2009, Bassani et al., 2009, Bewley et al., 1999, Capper et al., 1907, Lasaponara and Masini, 2011, Sarris et al., 2013).

α



Εικόνα 1: (α) Δορυφορική εικόνα CORONA της Κύπρου (1973/07/22) με χωρική ανάλυση 10m. (β) Η αρχαιολογική περιοχή του Κουρίου πριν και μετά τη συστηματική ανασκαφή του χώρου του Τμήματος αρχαιοτήτων στην εικόνα CORONA 1962/07/21 (αριστερά) και η αντίστοιχη εικόνα από Google Earth (δεξιά). Ο ευρύτερος αρχαιολογικός χώρος στο Ναό του Απόλλωνα Υλάτη (Κούριο) τη δεκαετία του 1960 στην εικόνα CORONA 1962/07/21 (αριστερά) και η αντίστοιχη εικόνα από Google Earth (δεξιά) (Agapiou et al., 2010a).

3. ΔΟΡΥΦΟΡΙΚΟΙ ΔΕΚΤΕΣ ΣΤΗΝ ΑΡΧΑΙΟΛΟΓΙΑ

Στη συνέχεια περιγράφονται βασικά χαρακτηριστικά των δορυφορικών δεκτών που συστηματικά χρησιμοποιούνται στην αρχαιολογική έρευνα.

- **Δορυφόρος Landsat (MSS / TM / ETM+):** Το διαστημικό πρόγραμμα Landsat είναι το αποτέλεσμα των προσπαθειών της NASA και το USGS για παρακολούθηση της γης από το διάστημα με τεχνικές τηλεπισκόπησης. Η πρώτη εκτόξευση δορυφόρου έγινε το 1972 (Landsat 1) και έκτοτε έχουν τεθεί σε τροχιά άλλοι 6 δορυφόροι (ο Landsat 6 δεν τέθηκε σε τροχιά λόγω προβλήματος). Ο δορυφόρος Landsat αποτελεί σύμφωνα με την Parcak (2009) τον πιο διαδεδομένο δορυφόρο για αρχαιολογικούς σκοπούς. Αυτό οφείλεται στο χαμηλό έως μηδαμινό κόστος αγοράς εικόνων, την παγκόσμια κάλυψη λόγω ηλιοσύγχρονης τροχιάς, αλλά και τις εικόνες αρχείου που διαθέτει από τη δεκαετία του 1970. Μια δορυφορική εικόνα τύπου Landsat καλύπτει μια έκταση της τάξης των 185 x 185 km^2. Ενδεικτικά αναφέρεται ότι μια εικόνα τύπου Landsat είναι σε θέση να καλύψει σχεδόν όλη την Κύπρο. Τα πολυφασματικά κανάλια του δορυφόρου καλύπτουν τόσο το ορατό όσο και το εγγύς και μέσο υπέρυθρο, ενώ παράλληλα έχει και αισθητήρες για την καταγραφή της θερμοκρασίας εδάφους. Το παγχρωματικό του κανάλι έχει χωρική ανάλυση της τάξης των 15 m, ενώ τα υπόλοιπα κανάλια έχουν ανάλυση 30 m με εξαίρεση το θερμικό που έχει ανάλυση 60 m. Τα δεδομένα Landsat μπορεί να αποκτηθούν σε μορφή GeoTiff δωρεάν μέσα από FTP έπειτα από αίτηση στην USGS (http://glovis.usgs.gov/).

- **Δορυφόρος CHRIS Proba:** Ο δορυφόρος Proba αναπτύχθηκε μέσα από το διαστημικό πρόγραμμα του Ευρωπαϊκού Διαστημικού Οργανισμού (ESA). Ο αισθητήρας CHRIS ονομάστηκε από τα αρχικά των λέξεων Compact High Resolution Imaging Spectrometer (Υψηλής Ανάλυσης Απεικονιστικό Φασματόμετρο Μικρού Μεγέθους). Εκτοξεύτηκε στις 22 Οκτωβρίου του 2001 και δίνει υπερφασματικές εικόνες σε 63 ξεχωριστά κανάλια, με χωρική ανάλυση 18 m. Το φασματικό εύρος του δορυφόρου επεκτείνεται από τα 415 nm μέχρι και τα 1050 nm. Στόχος του CHRIS Proba είναι κυρίως η αξιολόγηση των νέων τεχνολογιών από δορυφορικές απεικονίσεις και για αυτό άλλωστε αναφέρεται και ως πειραματικός δορυφόρος, αλλά παράλληλα και η χρήση των δεδομένων για περιβαλλοντικούς σκοπούς. Τα δεδομένα του δορυφόρου παραχωρούνται σε μορφή HDF μετά από έγκριση επιτροπής της ESA. Μια δορυφορική εικόνα τύπου CHRIS Proba καλύπτει μια έκταση 13 x 13 km^2. Τα δεδομένα CHRIS Proba είναι διαθέσιμα δωρεάν μετά από αίτημα στην ESA από το λογισμικό EOLI Catalogue.

- **Δορυφόρος EO-1 HYPERION:** Ο HYPERION, αποτελεί τον πρώτο δορυφόρο μιας νέας γενιάς διαστημικού προγράμματος της NASA και εκτοξεύτηκε το 2000. Κυρίως στόχος του δορυφόρου ήταν να συλλέξει πειραματικά δεδομένα για μελλοντικούς δέκτες. Κύριο χαρακτηριστικό του αισθητήρα του δορυφόρου HYEPRION είναι η πληθώρα των υπερφασματικών δεδομένων. συνολικά 220 ξεχωριστά κανάλια, και το φασματικό εύρος (356 nm - 2577 nm) που παρέχει. Η χωρική ανάλυση των δεδομένων ανέρχεται στα 30 m. Δεδομένα από τον HYPERION μπορεί να αποκτηθούν σε μορφή GeoTiff δωρεάν μέσα από FTP έπειτα από αίτηση στην USGS (http://glovis.usgs.gov/).

- **Δορυφόρος IKONOS:** Ο δορυφόρος IKONOS είναι ένας εμπορικός δορυφόρος υψηλής χωρικής ανάλυσης. Έχει εκτοξευτεί στο διάστημα το 1999 και μπορεί να δώσει εικόνες με χωρική ανάλυση έως και 1m στο παγχρωματικό του κανάλι ή 4m στα πολυφασματικά κανάλια. Η φασματική του ανάλυση επεκτείνεται από το ορατό μέχρι και το εγγύς υπέρυθρο, ενώ λήψη εικόνων σε μια περιοχή γίνεται κατόπιν προγραμματισμού. Αν και μπορεί να υπάρχουν διαθέσιμες εικόνες αρχείου IKONOS για μια περιοχή, εντούτοις αυτές δεν καταγράφονται από το δορυφόρο σε συστηματική βάση. Η ραδιομετρική ανάλυση του δορυφόρου είναι 11bit ενώ μπορεί να καλύψει μια περιοχή της τάξης των 13 x 13 km^2. Αξίζει να αναφερθεί ότι ο δορυφόρος IKONOS λαμβάνει και στερεοσκοπικές εικόνες οι οποίες μπορεί να χρησιμοποιηθούν για παραγωγή Ψηφιακών Μοντέλων Εδάφους ή Επιφανείας (DEM , DSM). Τα δεδομένα IKONOS είναι διαθέσιμα σε μορφή GeoTiff με κόστος από την GeoEye κατόπιν αίτησης.

- **Δορυφόρος QuickBird:** Ο συγκεκριμένος εμπορικός δορυφόρος της εταιρείας DigitalGlobe είναι στο διάστημα από το 2001. Ο συγκεκριμένος δορυφόρος συγκαταλέγεται αυτήν τη στιγμή στην τετράδα τηλεπισκοπικών δορυφόρων με την υψηλότερη χωρική ανάλυση μαζί με τους WorldView-1, WorldView-2 και GeoEye-1. Η χωρική του ανάλυση φθάνει σχεδόν το μισό μέτρο (0,60 m) στο παγχρωματικό φάσμα, ενώ στα πολυφασματικά κανάλια έχει ανάλυση 2,4 m. Η φασματική του ικανότητα είναι αντίστοιχη του δορυφόρου IKONOS (ορατό και εγγύς υπέρυθρο) ενώ μια εικόνα QuickBird καλύπτει έκταση στο έδαφος 16.5 x 16.5 km^2. Τα δεδομένα QuickBird είναι διαθέσιμα σε μορφή GeoTiff με κόστος από την DigitalGlobe κατόπιν αίτησης.

- **Δορυφόρος GeoEye-1:** ο δορυφόρος GeoEye-1 είναι ο πιο πρόσφατος δορυφόρος υψηλής διακριτικής ικανότητας που έχει εκτοξευτεί στο διάστημα (2008) και κατασκευάστηκε από την ομώνυμη εταιρεία. Η διακριτική ικανότητα του δορυφόρου είναι στα 0.41 m στο παγχρωματικό κανάλι και 1.65 m στα πολυφασματικά κανάλια. Η φασματική του ικανότητα περιορίζεται στο ορατό και εγγύς υπέρυθρο μήκος κύματος. Ο δορυφόρος GoeEye είναι επίσης εμπορικός και έτσι η κάλυψη σε μια περιοχή γίνεται σχεδόν αποκλειστικά μόνο μετά από αίτηση από ενδιαφερόμενους. Μια εικόνα GeoEye-1 καλύπτει έκταση 15 x 15 km^2.

- **Δορυφόρος CORONA:** οι δορυφορικές εικόνες τύπου CORONA αποτελούν εικόνες σε φιλμ και χρησιμοποιούνται για πρώτη φορά για σκοπούς αρχαιολογικής έρευνας στην Κύπρο. Οι παγχρωματικές εικόνες CORONA αποτελούν προϊόν του ψυχρού πολέμου. Κατά την περίοδο αυτή (1960 – 1972) έχει ληφθεί ένας μεγάλος όγκος εικόνων (πέραν των 860.000) σε διάφορες περιοχές του κόσμου από την U.S. Intelligence. Το φωτογραφικό φιλμ του κατασκοπευτικού δορυφόρου έπεφτε στη γη με τη βοήθεια αλεξιπτώτου και συλλέγονταν από ειδικά αεροσκάφη (βλ. Εικόνα 2). Οι εικόνες τύπου CORONA, οι οποίες αποδεσμεύτηκαν από το 1995 και μετά είναι διαθέσιμες σήμερα σε ψηφιακή μορφή και διατίθενται μετά από αίτηση με κόστος $30 ανά εικόνα.

Εικόνα 2: Αεροσκάφη ανακτούν την κυψέλη που περιέχει το φωτογραφικό φιλμ από το δορυφόρο CORONA.

4. ΕΡΕΥΝΗΤΙΚΟ ΠΡΟΓΡΑΜΜΑ ‘ATHENA’

Μέσα σε αυτό το ευρύτερο πλαίσιο εντάσσονται και οι προσπάθειες που καταβάλλονται από το Ερευνητικο Κέντρο Ερατοσθένης του Τεχνολογικού Πανεπιστημίου Κύπρου. Τη διεθνή αναβάθμιση του Ερευνητικού Κέντρου σε Κέντρο Αριστείας της Ανατολικής Μεσογείου προβλέπει νέο καινοτόμο ευρωπαϊκό πρόγραμμα.

Το κυπριακό Ερευνητικό Εργαστήριο «ΕΡΑΤΟΣΘΕΝΗΣ» του ΤΕΠΑΚ, εξασφάλισε χρηματοδότηση σχεδόν ενός εκατ. ευρώ, με συντονιστικό ρόλο στο τριετές (Δεκ. 2015-Δεκ. 2018) διευρωπαϊκό ερευνητικό έργο «ATHENA» που αφορά την συστηματική παρακολούθηση, την καταγραφή παραγόντων επικινδυνότητας και την προστασία της ευρωπαϊκής πολιτιστικής κληρονομιάς. Στο πολύ σημαντικό ευρωπαϊκό αυτό έργο θα συμμετέχουν και άλλα δύο πρωτοπόρα ερευνητικά κέντρα της Ευρώπης. Το Εθνικό Κέντρο Ερευνών της Ιταλίας (www.cnr.it) που είναι και το μεγαλύτερο δημόσιο ερευνητικό σώμα της χώρας, αλλά και το Γερμανικό Κέντρο Αεροδιαστημικής (www.dlr.de) που αποτελεί το εθνικό αεροναυτικό και διαστημικό κέντρο της Ομοσπονδιακής Δημοκρατίας της Γερμανίας και επανδρώνεται περίπου από 8.000 υπαλλήλους.

Απώτερος στόχος του έργου είναι η αποτελεσματικότερη και αμεσότερη παρακολούθηση μνημείων και αρχαιολογικών χώρων, ώστε να υπάρχει η δυνατότητα προληπτικής συντήρησης και προστασίας, πρόληψης έναντι φυσικών φαινομένων (π.χ. σεισμοί, κατολισθήσεις) και ανθρωπογενών επεμβάσεων (π.χ. συλήσεις, σύγχρονη πολεοδομική ανάπτυξη.

Το έργο υποστηρίζουν το Τμήμα Αρχαιοτήτων του Υπουργείου Συγκοινωνιών και Έργων, το Τμήμα Ηλεκτρονικών Επικοινωνιών του Υπουργείου Συγκοινωνιών και Έργων, το Cyprus Remote Sensing Society, ο Σύνδεσμος Κυπρίων Αρχαιολόγων και το Διεθνές Κέντρο Διαστημικών Τεχνολογιών για το Φυσικό και Πολιτιστικό Περιβάλλον της UNESCO (HIST).

Εικόνα 3: Το ερευνητικό πρόγραμμα ATHENA (*www.athena2020.eu*)

5. ΣΥΜΒΟΛΗ ΤΟΥ 'ATHENA'

Το «ATHENA» προκύπτει από το αγγλικό ακρωνύμιο του ευρωπαϊκού έργου «Επιστημονικό Κέντρο Τηλεπισκόπησης για την Πολιτιστική Κληρονομιά» («Spreading Excellence and Widening Participation»). Σκοπός του έργου είναι η παρακολούθηση, η καταγραφή και η ανάλυση αρχαιολογικών χώρων και μνημείων μέσω δορυφορικών απεικονίσεων και τεχνικών γεωπληροφορικής αξιοποιώντας τις πιο σύγχρονες τεχνολογικές εξελίξεις.

Το κυπριακό Ερευνητικό Κέντρο συμμετείχε στην Πρόσκληση Υποβολής Προτάσεων της Δραστηριότητας «Twinning» (H2020-TWINN-2015) του Προγράμματος. Σημειώνεται ότι, η συγκεκριμένη Πρόσκληση Υποβολής Προτάσεων είχε ως προαπαιτούμενο την εναρμόνιση και συνεισφορά της δραστηριότητας «Twinning» στη συνολική Στρατηγική Έξυπνης Εξειδίκευσης της χώρας, στην οποία εδρεύει ο Φορέας που συντονίζει την Πρόταση (με βάση την Πρόσκληση Υποβολής Προτάσεων, μόνο Φορείς από τις χώρες που χαρακτηρίζονται με χαμηλή απόδοση στους τομείς της έρευνας και καινοτομίας μπορούν να συντονίζουν τέτοια δίκτυα). Η ερευνητική πρόταση ATHENA καλύπτει πλήρως τους εθνικούς στόχους της Έξυπνης Εξειδίκευσης.

Ευχαριστίες

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ATHENA: CENTER OF EXCELLENCE IN CYPRUS IN THE FIELD OF REMOTE SENSING FOR CULTURAL HERITAGE IN THE AREAS OF ARCHAEOLOGY AND CULTURAL HERITAGE

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ABSTRACT:

In periods of economic instability, national considerations are overruling the process of European integration. Cultural Heritage (CH) is an integral element of a European set of values, and respect for heritage is vital for developing a common European identity. The CH sector has always been facing a number of challenges that have increased with the financial crisis that has hit Europe. To name a few, these include the decrease of public budgets, urbanisation, globalisation, and technological changes. Within this context, CH professionals are seeking to improve currently used methodologies, in order to better understand, protect and valorise the common European past and common identity.
The use of satellite and other remote sensing (RS) technologies has progressively been established in the field of environmental monitoring. In the domain of CH and landscape monitoring and in particular with regards to archaeological sites, these technologies have made a significant contribution to research and analysis over the past few decades. The potential use of RS for the understanding, documenting, monitoring and valorization of CH has long been recognised not only by RS experts and archaeologists, but also by the public authorities involved in heritage management, that suggested an increasing use of non-invasive technologies (Valletta Convention, 1992).
The ATHENA project aims to strengthen the Cyprus University of Technology's (CUT) Remote Sensing Science and Geo-Environment Research Laboratory in the field of Remote Sensing Archaeology by creating a unique link between two internationally-leading research institutions: The National Research Council of Italy (CNR) and the German Aerospace Centre (DLR). Through ATHENA, CUT's staff research profile and expertise will be raised, while the S&T capacity of the linked institutions will come out enhanced.

1. INTRODUCTION

Cultural Heritage (CH) remains an important sector for several economies within European Union. Several studies have shown that CH can provide an added value to the real economy of a country. As European Union (2015), highlights that Cultural heritage is now widely appreciated as an essential part of Europe's underlying socioeconomic, cultural and natural capital. This is a significant change in focus as cultural activities have traditionally been regarded as costs to society. The economic benefits of cultural heritage have most commonly been seen in terms of tourism.

According to studies, CH is also strong connected with tourism sector in Cyprus as well. Though that most tourists visit Cyprus for leisure, Cyprus aims at expanding its "special interest tourism", which includes cultural tourism, health and wellbeing, conference and events tourism, religious tourism, agrotourism, weddings and honeymoons and sports tourism. Cyprus' main advantages as a destination for cultural tourism are its culture and heritage, its clean archaeological sites, easy access to these and valued guide services. For instance, Paphos is a popular coastal town in the southwest of Cyprus. It offers spectacular scenery and some of Cyprus' finest beaches. Paphos offers ancient historical sites, some classified as world heritage sites by Unesco and an attractive harbour. It is expected that Paphos will be subject to intensified cultural activity, as it has been appointed by the EU to be a European Capital of Culture for 2017 (Cyprus Tourism Market Report, 2015). Recent statistics indicates that the archaeological site of Nea Paphos is the most visited monument in the island with more than 200,000 tourists per year.

Though several people recognise the importance of CH both in terms of sustainable economy as well as in terms of common memory and identity, several actions are needed to be taken so as to protect and safeguard these standing monuments. Nowadays, both natural and anthropogenic hazards are threatening CH sites and therefore a robust and systematic tool is needed to help stakeholders. In this perspective remote sensing technologies, including space observation and ground non-contact techniques can support stakeholders for monitoring and mapping both the monuments and sites as well their threats.

2. AIMS OF ATHENA PROJECT

Given the importance of remote sensing technologies for CH, ATHENA, a three-year duration project, aims to strengthen the Cyprus University of Technology's (CUT) in the field of Remote Sensing Archaeology by creating a unique link between two internationally-leading research institutions: The National Research Council of Italy (CNR) and the German Aerospace Center (DLR). The overall objective of the project is to expand the capabilities of the CUT members so as to establish a science centre in the eastern Mediterranean with advance remote sensing capabilities. This objective will be performed through training and other activities such as workshops and summer schools. ATHENA project also allows researchers to focus in new remote sensing technologies and to examine their potential use in archaeological research and prospection.

Such activities include among other the training of CUT personnel in advance remote sensing algorithms and approaches applied in archaeological research, risk estimation and damage assessment such as fire burned area mapping (Lanorte et al (2013). Object oriented analysis is expected to be carried out through different applications of the ATHENA project for classification purposes e.g. monitoring urban expansion in the vicinity of archaeological sites or detection of buried archaeological remains using segmentation techniques.

A recent example of the application of object oriented analysis is the detection of post-fire areas in the region of Troodos, where recent fires occurred in middle of July 2016 have burnt more than 16 square kilometers of forest. In this area, several important historical monuments exist including World Heritage monuments.

As shown in Figure 1, Landsat 8 multispectral image, taken at 24-06-2016 has been able to map the burnt area (see Figure 1, left, NIR-R-G composite). Segmentation analysis of the image was processed so as to create homogenous clusters of pixels in the image (Figure 1, right).

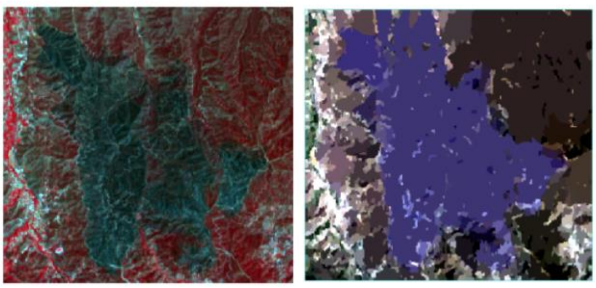

Figure 1: Left: NIR-R-G composite of the Landsat 8 (24-06-2016) and Right: Segmentation of the multispectral image.

The classification result was able to map the burnt areas using simple rule based approaches. This information was used so as to document the threat of the historical ekllisiastical churches of the sourrounding area, all protected and enlisted in the World Heritage mouments list (know as the ten byzantine chrches of Troodos). The risk map is shown in Figure 2, where burnt areas are indicated with orange colour, villages in red spots and the byzantine churches in green dots. As it is shown three of these ten monuments where in a close vicinity of fire event.

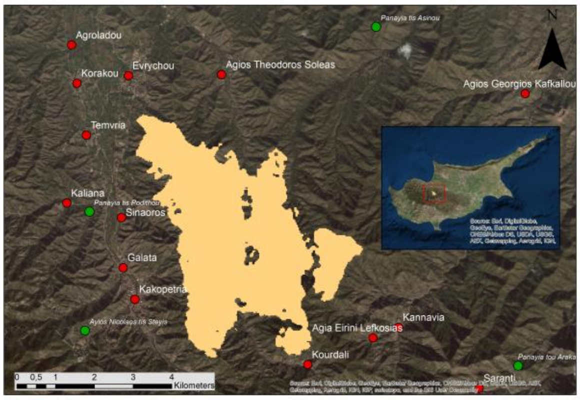

Figure 2: Map indicating the burnt areas (orange color), villages with red dots and the World Heritage Monuments in green dots.

3. DISCUSSION

Remote sensing datasets can provide helpful information for stakeholders so as to monitor cultural heritage sites and landscapes. Recent studies have indicated the importance of Cultural Heritage to real economy and tourism. Recent fires occurred in Cyprus have been used as a case study so as to demonstrate the capabilities of such technologies even in case of emergency.

As demonstrated in this case study, protection and monitoring of sites and monuments (either known or still un-known) is feasible using remote sensing data and remote sensing methodologies. Segmentation and rule based classification can be also used in this direction so as to identify in large scale any illegal activities.

The protection of CH by means of analysing satellite imagery is also in the focus of a EU "strategy for international cultural relations", where specifically the European COPERNICUS program should use its capabilities to monitor sites at risk and to evaluate damage (European Commission, 2016)

In this framework ATHENA project aims to build an advance remote sensing centre in the area of the Eastern Mediterranean and benefit from the new capabilities that new remote sensing sensors provide nowadays.

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SATELLITE BASED INVESTIGATION FOR DETECTION OF ANCIENT TOMBS' LOOTING IN CYPRUS

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Περίληψη/Abstract

Η παρούσα εργασία πραγματεύεται την ανάλυση πολυφασματικών δορυφορικών εικόνων και αεροφωτογραφιών υψηλής χωρικής ανάλυσης (WorldView-2) και RGB εικόνων από το Google Earth©, με σκοπό τη χαρτογράφηση και διαχρονική παρακολούθηση περιοχών, οι οποίες υπόκεινται σε συστηματική σύληση από τυμβωρύχους. Η έρευνα επικεντρώνεται στην ευρύτερη περιοχή της αρχαιολογικής θέσης «Άγιος Μνάσωνας» στο χωριό Πολιτικό της επαρχίας Λευκωσίας, όπου έχουν εντοπιστεί πέραν των δέκα συλημένων αρχαίων τάφων. Οι παράνομες αρχαιοκαπηλικές δραστηριότητες στην περιοχή πραγματοποιήθηκαν σε διαφορετικές χρονικές περιόδους με τις εισόδους των τάφων να εντοπίζονται σε βάθος περίπου τριών μέτρων από την επιφάνεια του εδάφους. Οι αναλύσεις των δορυφορικών εικόνων σε συνδυασμό με επιτόπια έρευνα έχουν δείξει ότι το φαινόμενο αυτό δεν είναι μεμονωμένο περιστατικό, αφού και άλλες περιοχές δυτικότερα της θέσης που εξετάζεται στην παρούσα εργασία, παρουσιάζουν ίχνη διατάραξης. Η προτεινόμενη μεθοδολογική προσέγγιση αποδεικνύει ότι η ανάλυση εικόνων και η επεξεργασία πολυφασματικών δορυφορικών δεδομένων υψηλής χωρικής ανάλυσης, προσφέρει τη δυνατότητα συστηματικής παρακολούθησης περιοχών αρχαιολογικού ενδιαφέροντος, με σκοπό την προστασία και διαφύλαξη της πολιτιστικής κληρονομιάς από παράνομες δραστηριότητες.

This study aims to present the results from the analysis of high resolution multispectral satellite and aerial images (WorldView-2) and RGB images from Google Earth© engine in order to map and diachronically monitor sites of archaeological interest that are endangered from looting. The research concerns the archaeological landscape of *Ayios Mnason* in Politico village, located in Nicosia district, where more than ten looted tombs have been identified. Some of these tombs have been disturbed in the past, while others by more recent illegal activities, detected in depth of more than three meters below ground surface. Image processing and *in situ* investigations evidenced that this phenomenon is not isolated, since other areas in the western part of the case study under examination in this paper, have been also disturbed. Overall, it is evident that image analysis and processing of high resolution multispectral satellite datasets, can be used for systematic monitoring of areas with archaeological interest, in order to protect and safeguard cultural heritage against illegal archaeological activities.

Keywords: archaeological looting, remote sensing, aerial images, satellite images, Cyprus, WorldView-2, Google Earth©

Introduction

Illegal archaeological activity consists one of the major anthropogenic hazards of cultural heritage threatening several important archaeological sites of Cyprus. While illicit trafficking has been secured under various international treaties (e.g. The Hague Convention 1954, UNESCO general Conference 1964, European Convention 1969 etc.), the local law and its subsequent amendments, still the illicit archaeological excavation and particularly tomb looting, as far as Cyprus concerns, is even today a serious infestation threatening the history and archaeology of the island. It is therefore evident that a robust and systematic tool is needed in assisting legal and local authorities and stakeholders.

To this end remote sensing technologies, including space observation and ground non-contact techniques, can be of a great support for mapping and monitoring both the archaeological sites and the natural and anthropogenic hazards threatening them. Through remote sensing technologies current threats could be detected, mapped and thus observed and monitored, while in some cases prediction of threats could be achieved. The *a priori* consideration of potential threats of 'sensitive' archaeological areas could consist of a strategic tool towards their prevention.

Within the last years remote sensing has been systematically employed to support various aspects of archaeological research (Agapiou & Lysandrou 2015) and cultural heritage sector (Tapete *et al.* 2016). More recently, greater attention was given towards the exploitation of earth observation techniques concerning the destructions made in war conflicted areas, including amongst others, the documentation of looted sites (Tapete *et al.* 2016). The investigation and monitoring of illicit archeological activity from space has been also studied in vast areas of archaeological interest upon limited surveillance means (Lasaponara *et al.* 2012; Lasaponara *et al.* 2014).

Even though remote sensing cannot stop looters, it can positively impact to the distant monitoring of large scale sensitive areas, providing fruitful information to stakeholders in order to identify looting signs, as well as to distantly and efficiently record and monitor these sites, also preventing further destructions of this kind.

For the aims of this study, multi-temporal aerial images taken during 1993, 2008 and 2014, as well as a multispectral high resolution WorldView-2 image and RGB images from Google Earth© engine were used. The multi-temporal analysis of the various data-sources included the creation of pseudo colour composites, the use of vegetation indices and Principal Component Analysis. The preliminary results from the image analysis of the above datasets are hereunder presented.

1. Case study area and methodology

The area under investigation is located in the south western part of the modern village of Politico, in Nicosia District. In this area, looted tombs have been identified in the past as well as in more recent years. The tombs are hewn out of the natural bedrock. Undisturbed tombs are difficult to be detected by means of aerial and/or satellite techniques due the fact that they are underground, in an approximate depth of 3 meters below surface. In contrast, signs of looted tombs are more likely to be observed and recognised in that way (Fig. 1).

The wider area of the Politico village consists of an intense archaeological territory, very important for the history of Cyprus, linked to the ancient city-kingdom of Tamassos. While several archaeological excavations took place in the past or are still taking place in the area of Politico (Politiko-Kokkinorotsos 2007: La Trobe University, Melbourne under Dr. David Frankel and Dr. Jenny Webb, Politiko-Troullia 2016: University of West Carolina Charlotte, USA under Dr. Steven Falconer and Dr. Patricia Fall), the necropolis under investigation here has never been excavated or studied. Even though this area has been declared as an ancient monument (Scheduled B' monument) and is protected by law, the looting not only has not ceased, but as will be shown hereunder, it has been augmented through the years.

Figure 1 Looted tomb. Looting has been achieved using mechanical equipment (depth more than three meters below ground surface).

The archaeological importance of the site is also documented in the first topographic map of Cyprus, drawn in the last quarter of the 19th century (Fig. 2).

Figure 2 Case study area as indicated in the Kitchener's map, drawn in the last quarter of the 19th century.

For the specific case study, three high resolution aerial datasets have been exploited: (a) a grayscale orthophoto aerial image taken in 1993 with 0.50 m pixel resolution; (b) an RGB orthophoto aerial image taken in 2008 with similar pixel resolution and (c) an RGB orthophoto aerial image taken in 2014 with pixel resolution of 20 cm. Further enhancement of the results obtained by the analysis of the abovementioned aerial datasets, was given through processing a high resolution WorldView-2 satellite image taken at 11th of June 2009 and examining the historical record of the Google Earth© engine.

2. Results

Initially, a critical interpretation of the aerial images has been accomplished (Fig. 3a-c). Subsequently, the datasets were overlaid and several colour composites have been created (Fig. 3d-f). For instance, Figure 3d presents a pseudo colour composite before looting events have taken place and therefore no anomalies are detected contrary to the rest of the composites (Fig. 3e-3f).

In addition, Principal Components Analysis (PCA) was applied to the aerial datasets. Figures 3g -3h present the first two Principal Components (PCs) while Figure 3i presents a pseudo colour from the first three PCs. In the latter, the looted areas are easily recognized.

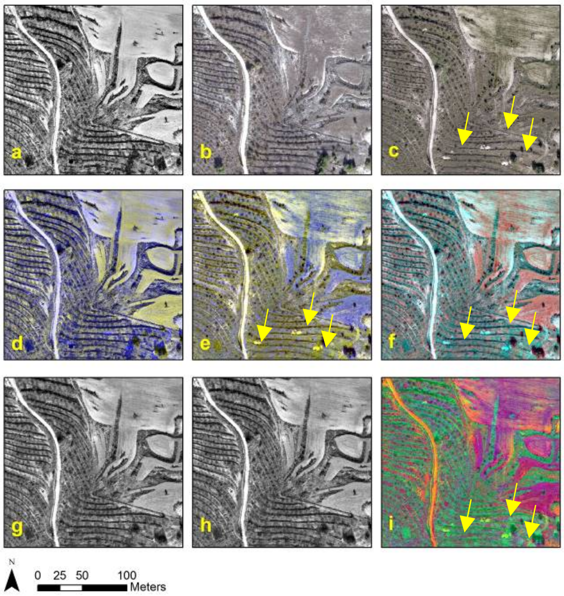

Figure 3 Grayscale orthophoto aerial image taken in 1993 with 0.50 m pixel resolution (a); RGB orthophoto aerial image taken in 2008 with similar pixel resolution (b); RGB orthophoto aerial image taken in 2014 with pixel resolution of 20 cm (c). Different colour composites have been created from these datasets (d-f), while (g-h) present the first two Principal Components (PCs) and (i) a pseudo colour from the first 3 PCs.

From the exploitation of the satellite datasets employed for this study, signs of looting have been identified in different periods covering a time span from 2008 until today (2016). Compared to the results of the aerial data, the satellite images have both identified even more looted tombs and provided information in relation to the looting period (Fig. 4).

Figure 4 shows the results from the image interpretation of WorldView-2 and Google Earth© images. Circles indicate areas looted at different times, demonstrating the expansion of looting from 2008 to 2016. Yellow circles are referring to the looted tombs that have also been identified in situ by the authors, while red circle defines a disturbed area detected only by satellite investigation.

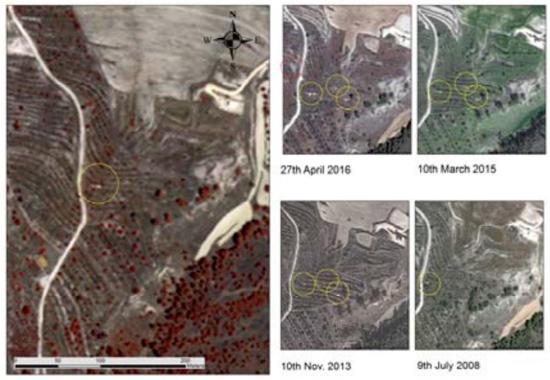

Figure 4 Left: Worldview-2 pseudo colour composite of 2009 indicating one looted tomb in circle. Right: screenshots from Google Earth© engine indicating looted tombs of the same area between 2008 and 2016.

Moreover, other algorithms have been tested at the WordView-2 dataset (see Figure 5) including several vegetation indices (such as the Normalised Difference Vegetation Index – NDVI; Difference Vegetation Index – DVI; Atmospheric Resistance Vegetation Index – ARVI etc.) and other indices like the Sum Green Index and Build Up Index as well as the orthogonal linear equations (Agapiou 2017). The latest techniques allow to the enhancement of the satellite image by creating a new 3D spectral space, which is linearly correlated to the initial spectral bands of the sensors, namely soil, vegetation and crop marks.

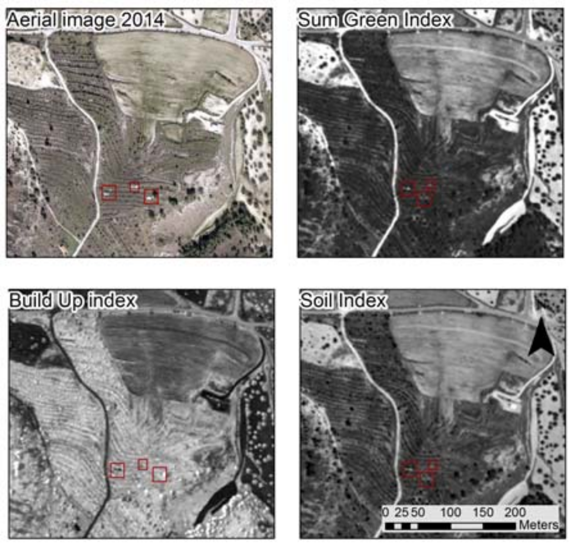

Figure 5 Aerial image indicating the looted areas in red squares (top left). The rest figures show the post-processing of the Worldview-2 image using different vegetation and other indices (such as Sum Green Index; Build Up Index) and linear orthogonal equations (soil component).

In addition, semi-automatic segmentation and classification techniques have been applied in both aerial and satellite data to evaluate their performance for the identification of looted areas. The semi-automatic segmentation was performed within the ENVI software using rule-based and object-oriented approach (Figures 6 and 7). Various parameters regarding the scale and the colour have been tested. Supervised and un-supervised classification of the image was also carried out within the same software. Un-supervised classification was performed using the ISODATA algorithm while supervised classifiers such as Mahalanobis distance and Support Vector Machine (SVM) have been applied. The classification was employed in order to examine whether the spectral properties of the looted areas could be detected from the multi-spectral sensor.

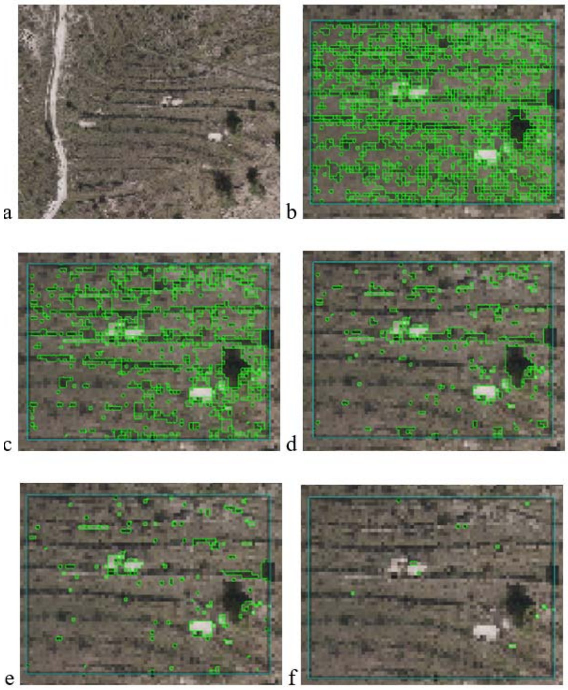

Figure 6 (a) Aerial image of 2014 (RGB) over the looted tombs; (b) Segmentation with 50 scale factor; (c) Segmentation with 60 scale factor; (d) Segmentation with 70 scale factor; (e) Segmentation with 75 scale factor and (f) Segmentation with 80 scale factor.

Figure 7: Simple rule base threshold values applied to the RGB bands of the orthophoto image acquired in 2014.

The overall results of the methodology for the specific case indicate that remote sensing techniques can be of great support to the authorities for monitoring tomb looting in vast archaeological landscapes, hard to be investigated systematically by other means.

Conclusions

The aim of the present paper was to evaluate the potential use of aerial and satellite datasets (object oriented classification compared to other classifiers, etc.) for monitoring tomb looting.

As demonstrated in this case study, protection and monitoring of sites and monuments (either known or still un-known) is feasible using remote sensing data and methodologies. While tomb looting identification was successfully achieved in the present research, this methodology could be useful (and further exploited) to identify other types of changes occurring in an archaeological landscape.

Remote sensing datasets can provide helpful information for stakeholders to monitor cultural heritage sites and landscapes. The piling of aerial and satellite data resulted in the identification of even more disturbed areas, upon different periods of time. The results clearly indicate that archaeological areas and landscapes can be monitored on a systematic basis to track and eventually prevent similar activities in the future, assisting local authorities to identify areas of high risk in relation to looting.

From an archaeological point of view, it is of great importance that this specific area, obviously a vast ancient cemetery laying to the west of Politico village has never been excavated and/or studied. The recurring loss of archaeological information and material from looting provokes an irreversible destruction to the archaeological layers and should be considered catastrophic for Cypriot archaeology.

It is important to highlight that the authors have accomplished in situ investigation prior and after image analysis, providing ground truth validation of the remote sensing results, thus permitting the evaluation of the techniques employed.

Acknowledgements

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Observing landscape changes around the Nicosia old town center using multi-temporal datasets

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Abstract. In 1980s a significant boom in construction industry was witnessed in Cyprus. This paper explores the changes of land use that have occurred over the past 30 years around the historical capital of Nicosia, in particular around the core of the historic city defined by the Venetian walls. Further to some Open geospatial Data available within the national and regional geo-portals, the research has focused on the use and exploitation of freely accessible satellite imagery (such as Landsat and Sentinel imagery) and other archive aerial datasets in order to observe the most recent modifications of the urban landscapes. The changes occurred over time were observed using multi-spectral multi-temporal dataset with main aim to create thematic maps for further interpretation. The changes were hence identified, mapped and structured so as to emphasise different types and density of urban development affecting the surrounding landscapes and potential “hot-spots”. Such observations could be a valuable input to the future urban development of Nicosia.

Keywords: historical cities, Nicosia, Cyprus, Earth Observation, Landsat, changing landscape

1 Introduction

Geo-spatial information is increasingly being used for purposes of territorial management as it has been recognized to be crucial when it comes to informed decision making processes that regard landscapes and environment. The nature of geo-information is in fact twofold - on one side the elaboration of such data is capable to describe phenomena that has already occurred (i.e. impact assessment purposes) and on the other side to provide us with simulations of possible further effects or occurrence (scenario modelling). In this paper authors opted for a combined and integrated use of multi-spectral, multi-temporal and multi-source data available over Cyprus in order to explore the contribution of freely available satellite imagery for monitoring of changes around the city of Nicosia and to suggest possibilities offered by such data for implementing the Open geospatial information available through national and EU repositories. Open geospatial Data approach was also of interest due to the recently

adfa, p. 1, 2011.

established national INSPIRE platform, implemented by the Department of Land and Surveying of the Republic of Cyprus [1]. In the framework of Open Government initiative, experts consider geospatial data to be significantly important category [2]. The possibility to access publicly collected and available data is retained crucial for the development of new and innovative applications useful for a variety of social domains [3]. Such approach that promotes the use and re-use of publicly collected data is actually encouraged by public policies for economic purposes [4].

This paper investigates the contribution of satellite imagery to non-space sectors such as built environment and urban development. The interaction between urban (built) environment and the surrounding landscapes was observed applying a combined and integrated use of multi-spectral and multi-temporal data (section 2). Section 3 illustrates the methodology applied on the satellite remote sensing data with focus on change detection, with illustration of the results in section 4. A discussion on the method and its use for purposes of decision making in urban contexts is provided in section 5. Paper concludes with inputs on the land use changes around the city of Nicosia and on possible contribution of the information deriving from the satellite imagery in the future decision-making processes that regard the island's capital.

2 Datasets

The main data used to observe the changes in landscape around Nicosia's walls were freely available satellite imagery Landsat (LT), described in Table 1.

Table 1. Landsat imagery used in the study

Year (date-month)	Satellite (Sensor)	Spatial resolution (m)		Spectral Resolution (nm) (only VIS-VNIR listed)
		Pan chromatic	VIS	
1987 (22-April)	LT5 (Thematic Mapper – TM)	15	30	450 -900
2003 (25-Sept)	LT5 (Thematic Mapper – TM)	15	30	450 -900
2016 (5-April)	Landsat8 Operational Land Imager (OLI)	15	30	433 -885

The images were accessed and downloaded from the geo-portal of the Geographical Survey of United States (USGS) for the years 1987, 2003 and 2016. This choice was made in order to investigate changes in the period of 80s and 90s (years of construction sector "boom" recorded in Cyprus) [5] and to observe possible modifications in urban fabric in the years after Cyprus accession to the European Union in 2004. PCA methodology was applied as it is frequently used to understand interactions between landscape and urban sprawl. In 2015, for example, Agapiou et al. [5], use PCA to determine areas of Paphos municipality that have undergone dramatic change in their land use for the period 1984-2010.

Fig. 1 above shows Nicosia observed in all three images in Red – Green – Blue (RGB) bands i.e. the band combination that corresponds to the human vision. Below the same area as seen in band combination NIR – R – G that enhances the presence of vegetation (in red). This paper concentrates on the changes occurred in the part of Nicosia under administration of Republic of Cyprus, south of the buffer zone area.

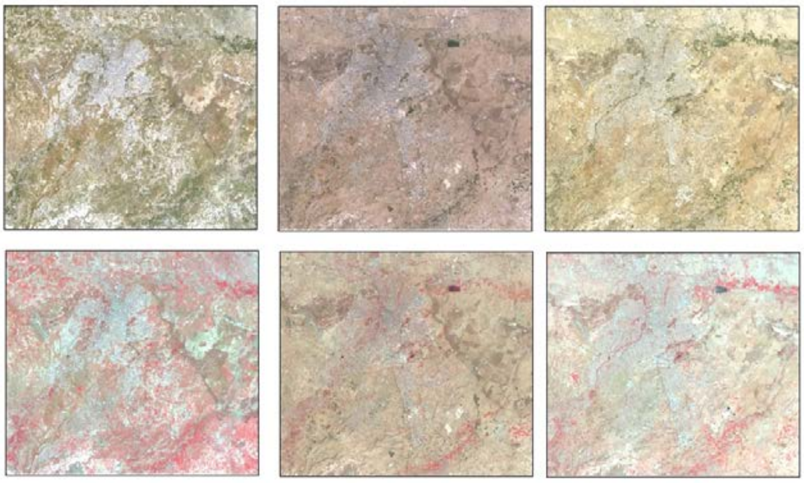

Fig. 1. Nicosia Municipality seen in RGB (above) and as NIR – green – blue (below).

3 Methodology

3.1 Creation of multi-spectral multi-temporal imagery using Landsat data

In order to observe the land changes using this multi-spectral imagery over a period of time, first it was necessary to build "stack layers" composed of two images. This was performed for three pairs (1984-2003; 1984-2016 and 2003-2016) using ERDAS Imagine 2010 software©. The images obtained in such a way are hence referred to as multi-spectral multi-temporal imagery. However, it is important to mention that a selection of bands for every image was made, according to their suitability for observing changes of construction and vegetation areas i.e. the urban development and possible landscape changes around inhabited spaces. Table 2 reports these combinations for all three pairs used.

Table 2. Landsat satellite imagery and respective bands used for creation of multi-spectral multi-temporal pairs.

Image pair	**Single satellite image per year**	**Band number in the original image (wavelength)**	**Band number in multi-temporal image**
Pair 1987-2003	LT5 1987	Band 1 – blue (0.45-0.52)	1
		Band 2 – green (0.52-0.60)	2
		Band 3 – red (0.63-0.69)	3
		Band 4 – Near Infrared (0.77-0.90)	4
		Band 5 – short-wave Infrared (1.55-1.75)	5
		Band 6 – Thermal Infrared (10.40-12.50)	6
		Band 7 – red (2.09-2.35)	7
	LT5 2003	Band 1 – blue (0.45-0.52)	8
		Band 2 – green (0.52-0.60)	9
		Band 3 – red (0.63-0.69)	10
		Band 4 – Near Infrared NIR (0.77-0.90)	11
		Band 5 – short-wave Infrared SWIR (1.55-1.75)	12
Pair 1987-2016	LT5 1987	Band 1 – blue (0.45-0.52)	1
		Band 2 – green (0.52-0.60)	2
		Band 3 – red (0.63-0.69)	3
		Band 4 – Near Infrared (0.77-0.90)	4
		Band 5 – short-wave Infrared (1.55-1.75)	5
		Band 6 – Thermal Infrared (10.40-12.50)	6
		Band 7 – red (2.09-2.35)	7
	LDCM 8 2016	Band 2 – blue (0.45-0.51)	8
		Band 3 – green (0.53-0.59)	9
		Band 4 – red (0.64-0.67)	10
		Band 5 - NIR (0.85-0.88)	11
		Band 6 – short-wave Infrared (1.57-1.65)	12
		Band 7 - SWIR (2.11-2.29)	13
		Band 8 Panchromatic (0.50-0.68)	14
Pair 2003-	LT 5 2003	Band 1 – blue (0.45-0.52)	1

2016		Band 2 – green (0.52-0.60)	2
		Band 3 – red (0.63-0.69)	3
		Band 4 – Near Infrared NIR (0.77-0.90)	4
		Band 5 – short-wave Infrared SWIR (1.55-1.75)	5
	LDCM8 2016	Band 2 – blue (0.45-0.51)	6
		Band 3 – green (0.53-0.59)	7
		Band 4 – red (0.64-0.67)	8
		Band 5 - NIR (0.85-0.88)	9
		Band 6 – short-wave Infrared (1.57-1.65)	10
		Band 7 - SWIR (2.11-2.29)	11
		Band 8 Panchromatic (0.50-0.68)	12

For experiment purposes an additional image combining all three images was built following the same procedure. In this case, a composite image of 19 bands was obtained, as illustrated in Table 3.

Table 3. Landsat satellite imagery and respective bands used for creation of a composite multi-spectral multi-temporal image.

Composite Image	Single satellite image per year	Band at the origin and its wavelength domain	Band number in the multi-temporal image
1987 – 2003 - 2016	LT5 1987	Band 1 – blue (0.45-0.52)	1
		Band 2 – green (0.52-0.60)	2
		Band 3 – red (0.63-0.69)	3
		Band 4 – Near Infrared (0.77-0.90)	4
		Band 5 – short-wave Infrared (1.55-1.75)	5
		Band 6 – Thermal Infrared (10.40-12.50)	6
		Band 7 – red (2.09-2.35)	7
	LT5 2003	Band 1 – blue (0.45-0.52)	8
		Band 2 – green (0.52-0.60)	9
		Band 3 – red (0.63-0.69)	10
		Band 4 – Near Infrared NIR (0.77-0.90)	11
		Band 5 – short-wave Infrared SWIR (1.55-1.75)	12
	LDCM8 2016	Band 2 – blue (0.45-0.51)	13
		Band 3 – green (0.53-0.59)	14
		Band 4 – red (0.64-0.67)	15

		Band 5 - NIR (0.85-0.88)	16
		Band 6 – short-wave Infrared (1.57-1.65)	17
		Band 7 - SWIR (2.11-2.29)	18
		Band 8 Panchromatic (0.50-0.68)	19

Fig. 2 shows two scenarios A and B with hatched buffer zone (left) and with buffer zone show as outline (right). The couple of images A refer to a stack image pair 1987-2016 observed with a combination 1,8, 14 i.e. showing the blue bands of both images and using panchromatic band to enhance the spatial resolution. Couple B refers to a stack of all three images (Table 2) observed with a band combination 1, 8, 13 i.e. the blue bands in all three years. Such visualization criteria was chosen because man-made structures (and materials such as cement) are more easily distinguished in this range of spectrum.

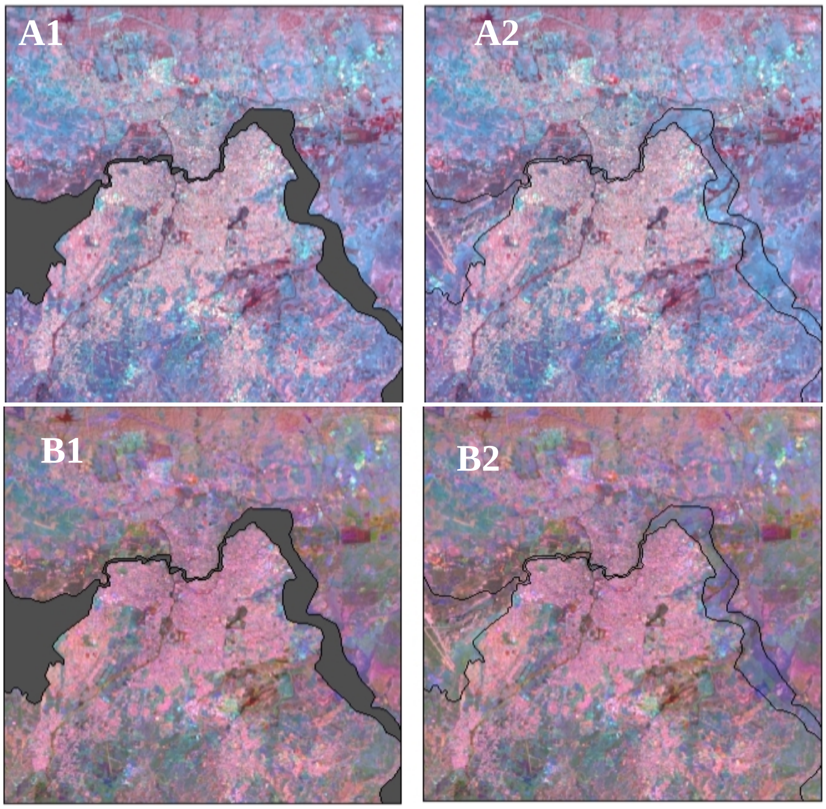

Fig. 2. Blue band combinations: A) 1987-2016 image observed in band combination 1, 8 and 14 (above) and B) 1987-2003-2016 image observed in band combination 1, 8, 13 (below).

3.2 3.1 Principal Component Analysis of multi-spectral multi-temporal data

In order to analyze these first observations, a spectral enhancement technique was performed using a Principal Component Analysis (PCA). The parameter of 5 elements was used in order to have a significant qualitative gradient of changes in a range from 1 to 5 (with 1 referring to the most and 5 referring to least significant changes, respectively). Equivalent analysis was made for a multi-temporal image combining all three datasets. The image obtained however results in a complicated set of information that regards almost 30 years. In order to comment such image a more thorough background in terms of historical information and documentation is needed.

4 Results

The results obtained using the PCA is illustrated in Figure 4. It is to be noted that such images appear in false-colour meaning that RGB channels are attributed to single elements of the PCA. Here the band combination used was 1, 2, 4 meaning that higher changes are observed in channels of Red and Green (1 and 2 respectively) while milder changes are observed in Blue channel (4 on the scale of 1-5).

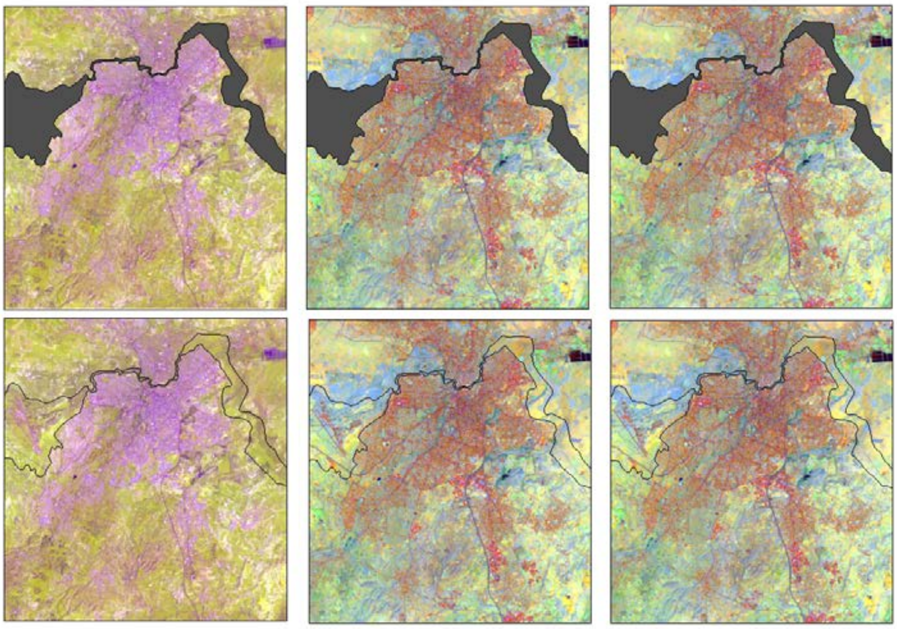

Fig. 3. Principal Component Analysis for image pairs: 1987-2003 (left); 2003-2016 (midfle) and 1987-2016 (right). Buffer zone is shown as hatched (above) and as outline only (below).

Hence, the colours seen on the image do not have an absolute value but are an indication of landscape change in the cover (and hence use) observed and it requires further qualitative and quantitative interpretation. A closer look on the walled city of Nicosia and its southern area within the PCA image 1987-2016 (Fig. 5) show some significant changes around the city walls (white dashed lined), just out of the walls and along the main transport arteries of the city (red colour).

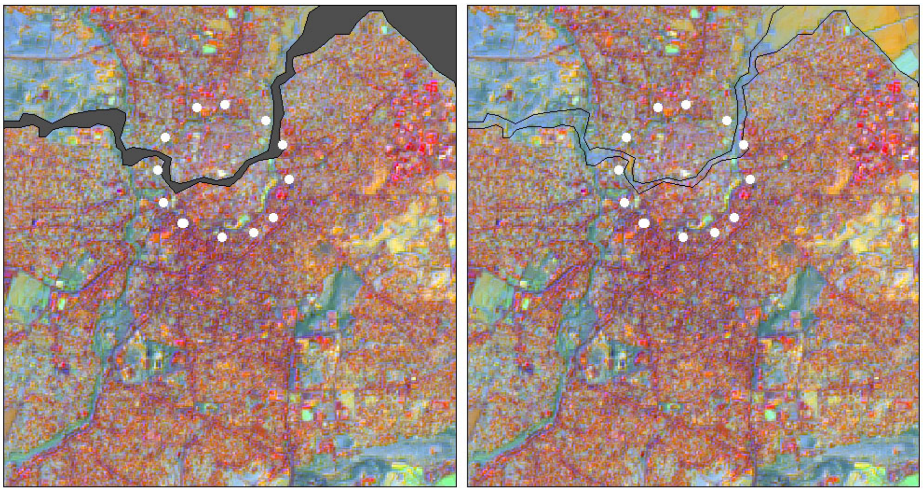

Fig. 4. PCA of the image pair 1987-2016, a close-up on southern Nicosia.

Such observations were identified as 'hot-spots' and were further examined observing the values of sample pixels across all the bands used in both images.

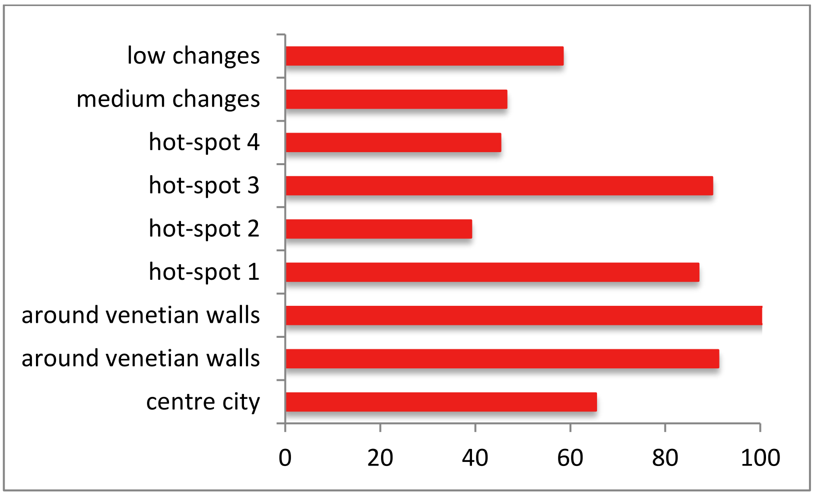

Fig. 5. The absolute difference in blue bands in 1987 and in 2016 for all 9 sample points

Using 1987-2016 PCA image as a reference, a sample of 9 points was selected (points within the walled city, on the walls and out of the walls on ‘hot-spots’ and on areas with medium and low change-rate). Choosing the blue band as the most suitable one for observations of changes in construction, the absolute differences in reflectance values were observed in bands 1 and 8 of the image pair 1987-2016 (Table 2), shown in Fig. 5. The difference value is not steady but shows fluctuation: such behavior could indicate changes in the urban environment (such as demolition or new construction) for example in point 3 (around Venetian walls) or in point 6 (hot-spot 3). Further, the four pixel samples corresponding to ‘hot-spots’ were examined for their reflectance values in Near Infrared (NIR) band in both years (i.e. bands 4 and 11 from Table 2). Fig. 6 shows that differences in reflectance of ‘hot-spots’ 1, 2 and 3 have a similar trend, while it is different for ‘hot-spot’ 4. NIR range of the spectrum this band is particularly suitable for detecting changes in vegetation. This observation could hence be an indication of change in vegetation cover in the ‘hot-spot 4’.

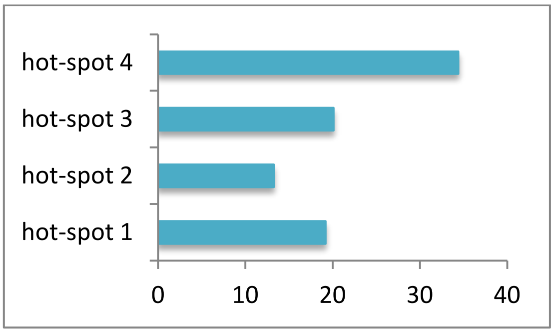

Fig. 6. The absolute difference in NIR bands in 1987 and in 2016 for all ‘hot-spots’

5 Discussion

The results illustrated show that quite a few areas in Nicosia have been subject to land cover change and hence probably their land use. The PCA seems to be an adequate method for qualitative analysis and useful for identification of ‘hot-spots’ i.e. areas mostly subject to change. The limits of this approach is that areas cannot be assumed as ‘hot-spots’ only upon the investigation of satellite imagery but they need to be further examined using urban masterplans or technical maps. In addition to reflectance pixel values, the assumptions made on the type of land cover change are to be further elaborated using historic data and in-situ measurements, also due to the limit of the image spatial resolution. The method proposed can be however suitable for two reasons: 1) it can provide an overview of the changes on a territorial scale of entire municipalities (or even larger areas) and 2) it can help to identify specific areas of the city that have been subject to change and that require further investigation.

6. Conclusions

The study here illustrated was an attempt to observe changes in urban environment of the Nicosia municipality, in particular in the southern area around the walled historic city. The methodology employed regards the use of freely available satellite imagery that was examined using multi-spectral multi-temporal pairs of images. Further to the visual interpretation, the study illustrates a spectral enhancement method using a PCA. The results show some clear changes in the urban fabric in southern area of the walled city of Nicosia, helping to identify several significant 'hot-spots'. Possible use of such result could be seen in the development and implementation of the urban masterplans or planning the construction works that could have high impact on the historic urban structure e.g. new high speed transport connections, proximity of larger constructions to sensitive areas such as Venetian walls and so forth. However, it is important recall that in order to quantify and describe the changes more precisely, further in-situ measurements and comparison with historic information such as maps and aerial images needs to be performed. In such a way, it would be possible correlate in an even more significant manner the observations coming from satellite imagery with changes in the urban scenario that have occurred over the past three decades.

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Searching data for supporting archaeo-landscapes in Cyprus: an overview of aerial, satellite and cartographic datasets of the island

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ABSTRACT

The landscape of Cyprus is characterized by transformations that occurred during the 20th century, with many of such changes being still active today. Landscapes' changes are due to a variety of reasons including war conflicts, environmental conditions and modern development that have often caused the alteration or even the total loss of important information that could have assisted the archaeologists to comprehend the archaeo-landscape.

The present work aims to provide detailed information regarding the different existing datasets that can be used to support archaeologists in understanding the transformations that the landscape in Cyprus undergone, from a remote sensing perspective. Such datasets may help archaeologists to visualize a lost landscape and try to retrieve valuable information, while they support researchers for future investigations. As such they can further highlight in a predictive manner and consequently assess the impacts of landscape transformation -being of natural or anthropogenic cause- to cultural heritage.

Three main datasets are presented here: aerial images, satellite datasets including spy satellite datasets acquired during the Cold War, and cadastral maps. The variety of data is provided in a chronological order (e.g. year of acquisitions), while other important parameters such as the cost and the accuracy are also determined. Individual examples of archaeological sites in Cyprus are also provided for each dataset in order to underline both their importance and performance. Also some pre- and post-processing remote sensing methodologies are briefly described in order to enhance the final results. The paper within the framework of ATHENA project, dedicated to remote sensing archaeology/CH, aims to fill a significant gap in the recent literature of remote sensing archaeology of the island and to assist current and future archaeologists in their quest for remote sensing information to support their research.

Keywords: Remote Sensing Archaeology, Cyprus, Crop marks, Soil Marks, Archeolandscapes, ATHENA project

1. INTRODUCTION

The potential of geospatial data to access and analyse historical digital datasets for landscape and territorial analysis has been discussed in the past by several researches [1-3]. For instance, [2] has demonstrated how archive Digital Elevation Models (DEM) produced by aerial images can be exploited along with recent datasets from Airborne Laser Scanner (ALS) in order to generate automatic landscape changes through time. The study of landscape transformations is

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increasingly relying upon sophisticated geo-services based on spatial information [4]. Inside the range of the current digital era accompanied by new kind of data sources and products, archaeologists seek to recover lost information of landscapes aiming at a better understanding and interpretation of archaeological findings. To do so, interpretation of archive aerial and satellite datasets is performed along with historical maps and recently acquired datasets. This procedure is usually undertaken into a Geographical Information System (GIS) which has the capability to visualize any other kind of new "big data" [5]. All these datasets can be inserted as time-stamped thematic layers into a GIS environment and then overlapped with other kind of geospatial information, also creating a basis for archaeological prediction models [6]. This procedure allows archaeologists to uncover the lost landscape, especially in regions that have been heavily transformed in recent years due to modern infrastructures including urban expansion and land use changes. As recent examples have shown for the area of Cyprus, urban expansion especially in the south cities of the island has be estimated to 300% for the period 1984 – 2010 [7]. The benefits from passive and active satellite, aerial and close range remote sensing approaches, including archived and declassified satellite data, have been already acknowledged by several archaeological communities in Europe [8-13], Asia [14] and America [15] and great efforts have been carried out in the last years towards these directions. However, the accessibility to archive datasets is not an easy task for some regions. It should be noticed that archive information is usually found scattered and the information (metadata) associated with this data is also confused. Such examples are demonstrated within this paper, which aims to provide a basic catalogue and information related with remote sensing datasets for supporting archaeological research in Cyprus. Such information is still fragmental for many archaeologists and archaeological missions working in the island. Therefore, this paper points to fill this gap and at the same time to assist current and future archaeologists in their research using remote sensing datasets.

2. CASE STUDY AREA

The island of Cyprus is found in the eastern part of the Mediterranean Sea and it's the third largest island (Figure 1). It lies between latitudes 34° and 36° N, and longitudes 32° and 35° E. of the World Geodetic System (WGS). Troodos Mountains and Kyrenia Range are the two main mountainous regions of the island found in the central and northern part respectively. Between these two mountains is located the central plain of Mesaoria. The highest point on Cyprus is Mount Olympus at 1,952 m located in the center of Troodos range. The total size of the island is estimated to 9.251km^2 with more than 645 km of coastline. Cyprus is about 240 km long and 100 km wide. The earliest confirmed site of human activity on Cyprus is Aetokremnos, situated on the south coast, indicating that hunter-gatherers were active on the island from around 10,000 BC. The multiple archaeological vestiges of the island comprise an undisputable testimony of its long history extending until the late medieval and ottoman eras. Still today, several archaeological missions both local and foreign are intensively investigating various sites revealing more aspects on the Cyprus long history.

Figure 1: Cyprus island as captured from the Sentinel-2 sensor on the 11/03/2016 (Copernicus Sentinel data (2015)/ESA©)

3. LOCAL DATASETS

3.1 Archive maps

The first cadastral maps of Cyprus are dating back to the late 19th century. During the period 1878 until 1882 Lord Kitchener created the first topographical map of the island, after he has just completed the survey of Western Palestine. The scale of the map is 1 inch to 1 mile, and several useful information can be found there. In addition to the topographical terrain, presented with its contours, also ruins, watermills and other important monuments are placed in the map. An example of the map over the archaeological sites of Nea Paphos and Tombs of the Kings can be seen in Figure 2 (left) [16]. This map is of great historic value for the archaeological surveys of Cyprus since it mapped for the first time “monuments” and “sites” of archaeological interest. The geolocation of this information however might be imprecise, and therefore archaeologists should be cautious when retrieving archaeological information out of this kind of datasets.

Since then several cadastral maps have been generated for Cyprus. These can be found in two different coordinate systems (i.e. Casini and LTM projections), depending on the period of the production of the maps, and in different scales according to the location. In general towns and village centers have larger scales, so further information and details can be tracked in those maps. Such maps are very useful for archaeologists working on the island for two reasons. On the one hand they can identify the sheet / plan and parcel number of their interest in order to use this combination for any formal request to the Department of Antiquities and to the Department of Land and Surveyors, and on the other hand they can still find hidden information in these maps such as Ancient Monuments (A.M) (see Figure 2, right). All these maps can be found in the Department of Land and Surveyors. The latest year of modification of these maps is mentioned in the lower part of the map providing in this way a terminus ante quem.

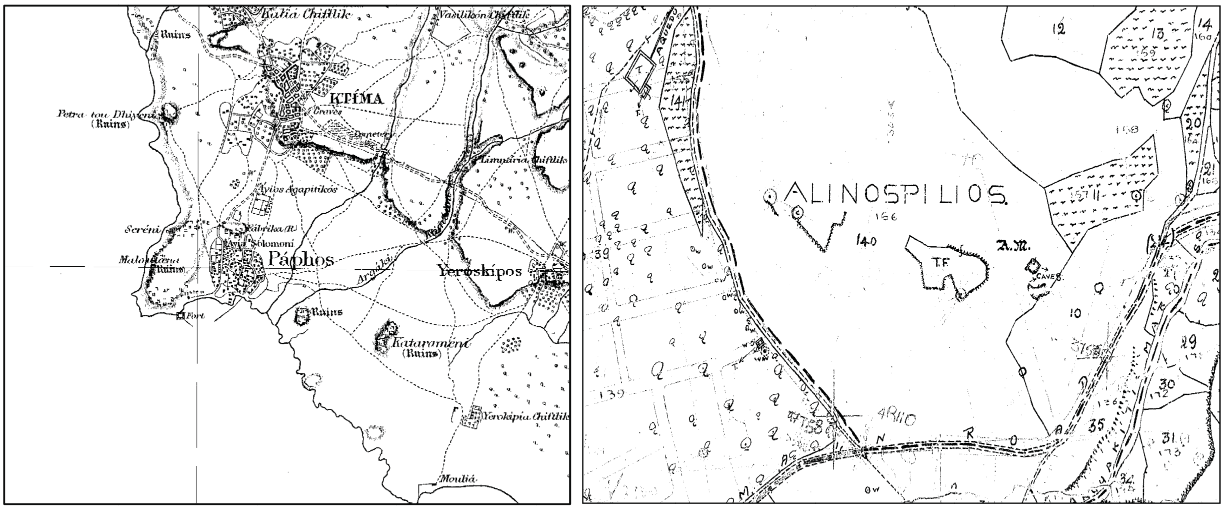

Figure 2: Kitchener’s map over the archaeological sites of Nea Paphos and Tombs of the Kings (left) and cadastral map from the area of *Anavargos* village (locality *Alinospilios* also known as *Ellinospilios* and *Ellinospilioi*) indicating some Ancient Monuments (A.M), more specifically a partially preserved Hellenistic-Roman necropolis (right) (from Department of Land and Surveyors of Cyprus ©)

3.2 Archive aerial images

In Cyprus, compared to other areas of Europe, only one systematic mapping using aerial photographs has been carried out in the whole island. This was completed in 1963, just after the independence of Cyprus in 1960. The greyscale images were taken in stereo-pairs so 3D models of the topography of that period can be generated using standard photogrammetric procedures. These images can be also found as orthophotos (i.e. images corrected from elevation distortions etc.). The aerial images archive of Cyprus is of invaluable importance for archaeological investigations on the island, since it comprises images that have captured the island’s icon prior to any modern development, such as the constructions of dams and roads, the urban expansion and other infrastructural work of natural changes. However, it

should be noticed that these images exhibit a low Signal-to-Noise Ratio (SNR), which hinders the interpretation of the data. Post-processing is sometimes necessary in order to enhance and improve the quality of the images.
The next systematic airborne campaign was only taken in 1993, but it was restricted to the southern part of the island. The acquired images were once again panchromatic and stereo. True colour images (RGB) of the southern part of Cyprus have been acquired only in 2008 and 2014. The latest aerial survey was of high quality in terms of spatial resolution (25 cm ground sampling distance) indicating how technological improvements (i.e. oblique images) have changed the traditional aerial surveys. These images are useful in order to detect, map and visualize transformations of Cyprus' landscape. Indeed, in specific areas of the island such as the area of Paphos [7], the land use changes that occurred during the last decades were dramatic (300% urban expansion) and rapid. Automatic change detection techniques could be applied so as to automatically or semi-automatically map these land use changes, but can be restricted due to the spectral resolution of the datasets (panchromatic and RGB images). Therefore, the manual digitization persists as the most common way to map the land use and land cover changes.
Archaeologists can purchase archive aerial images from the Department of Land and Surveyors, in order to map the changes over the landscape through the period from 1963 until 2014 (for the southern part of the island only). An example of the orthophotos taken in 2008 and 2014 over the archaeological site of Nea Paphos is presented in Figure 3 (e and f respectively). It is important to note that all these datasets exhibit a high spatial resolution (meter or sub-meter ground sampling distance). However, since the aerial images were taken mainly for the needs of the Department of Land and Surveyors, this resolution might be still insufficient to support micro-scale archaeological surveys (i.e. archaeological excavation), but is considered more appropriate for landscape scale studies.

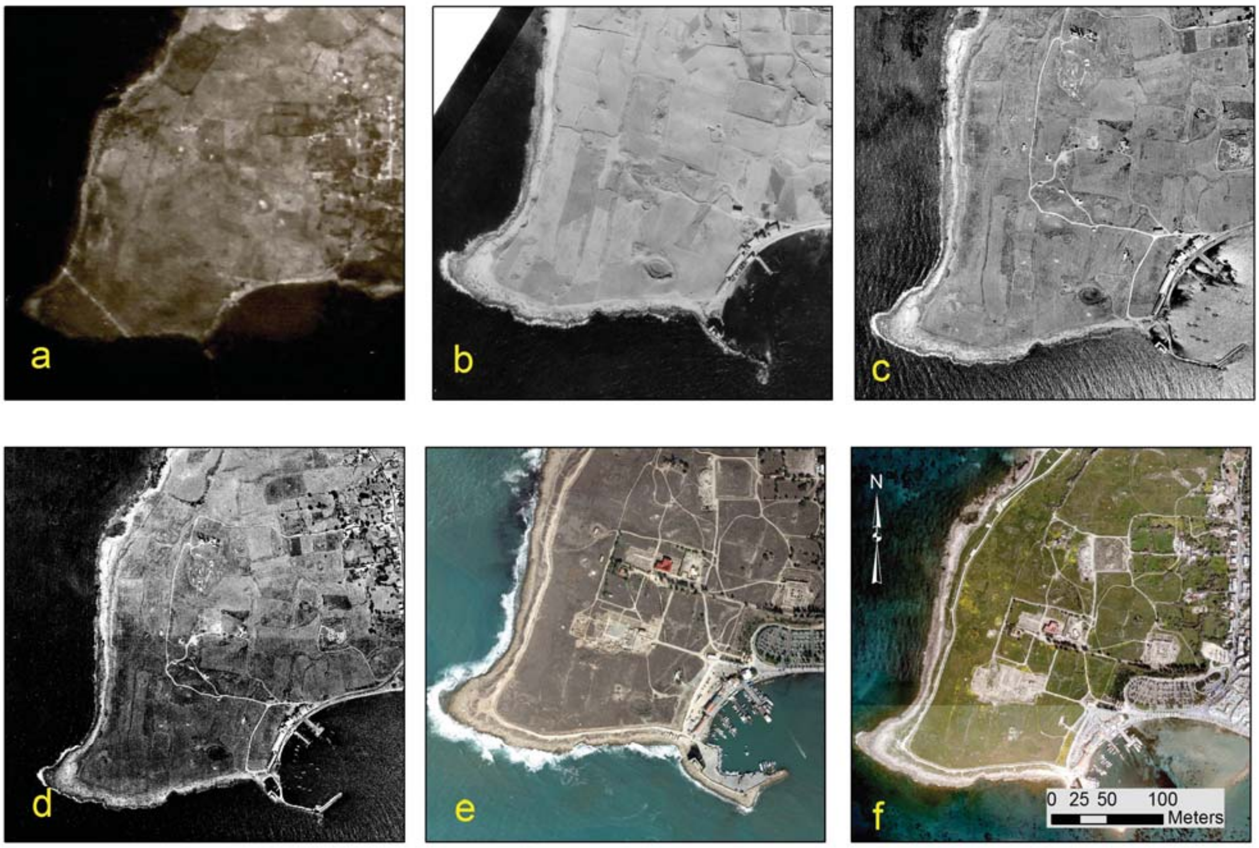

Figure 3: Aerial images taken over the archaeological site of Nea Paphos: (a) aerial image of Cyprus before the Second World War (b) aerial image of 1945 taken from RAF; (c) aerial image taken in 1962; (d) aerial image of 1993; (e) aerial orthophoto of 2008 and (f) aerial orthophoto of 2014

Infrequently, further aerial images of Cyprus from different periods can be found, as for instance the aerial images of Royal Air Force (RAF) that captured some sites of the island during the 40's. Occasionally, these images are of high quality and several crop and soil marks can be spotted as seen in Figure 3b. However, in other aerial images,

interpretation can be problematic due to the noise of the datasets. It has been demonstrated in [17] that such datasets might be fused together using pan-sharpening techniques in order to retrieve the lost archaeological marks and therefore assist archaeologists for better understanding a site. Other aerial images taken during the 70's are also available from the Department of Land and Surveyors.
Special attention should be given to the oldest aerial archive datasets –up to our knowledge- that cover the whole island of Cyprus. The images were taken before (or during?) the second World Word and now are catalogued in the Istituto Geografico Militare of Italy. These images are shown in a scale of 1:25000 and their original printed size is 698 X 606 mm. A single image is usually a mosaic of three or more other aerial images and all these are stacked and joined together to complete an area. Although the quality of these images is not sufficient for micro-surveys, their historical value is of great importance since they are taken prior to any modern evolution of the island and therefore significant changes of the landscape can be observed. An example is shown in Figure 3a where the modern city of Paphos consisted in only two small villages, those of Ktima and Paphos. A further observation in landscape level comprises in the viewing the main rivers of Cyprus once flowing into the sea, a lost 'picture' of modern landscape due to the construction of dams (Cyprus has a total of 108 dams and reservoirs).

4. OTHER DATASETS

4.1 Satellite images

A variety of satellite multi-temporal datasets is currently available to researchers. Conversely, the majority of the high resolution satellite images were only acquired after 1999, when the first commercial satellite sensor with these characteristics (IKONOS) was launched. Since then, other multispectral sensors have been sent into space including QuickBird, GeoEye, WorldView, Pleiades etc. Satellite images dating before 1999 that can be used to support archaeo-landscape studies are Landsat and SPOT 4. The spectral range of these images include the RGB and near infrared / middle infrared parts of the spectrum. It should be noticed that Landsat images are freely distributed from USGS: however, the spatial resolution of Landsat / SPOT 4 images is approximately one order of magnitude worse than the previously described satellites, and therefore might not fully support landscape studies. An example of these images is shown in Figure 4.

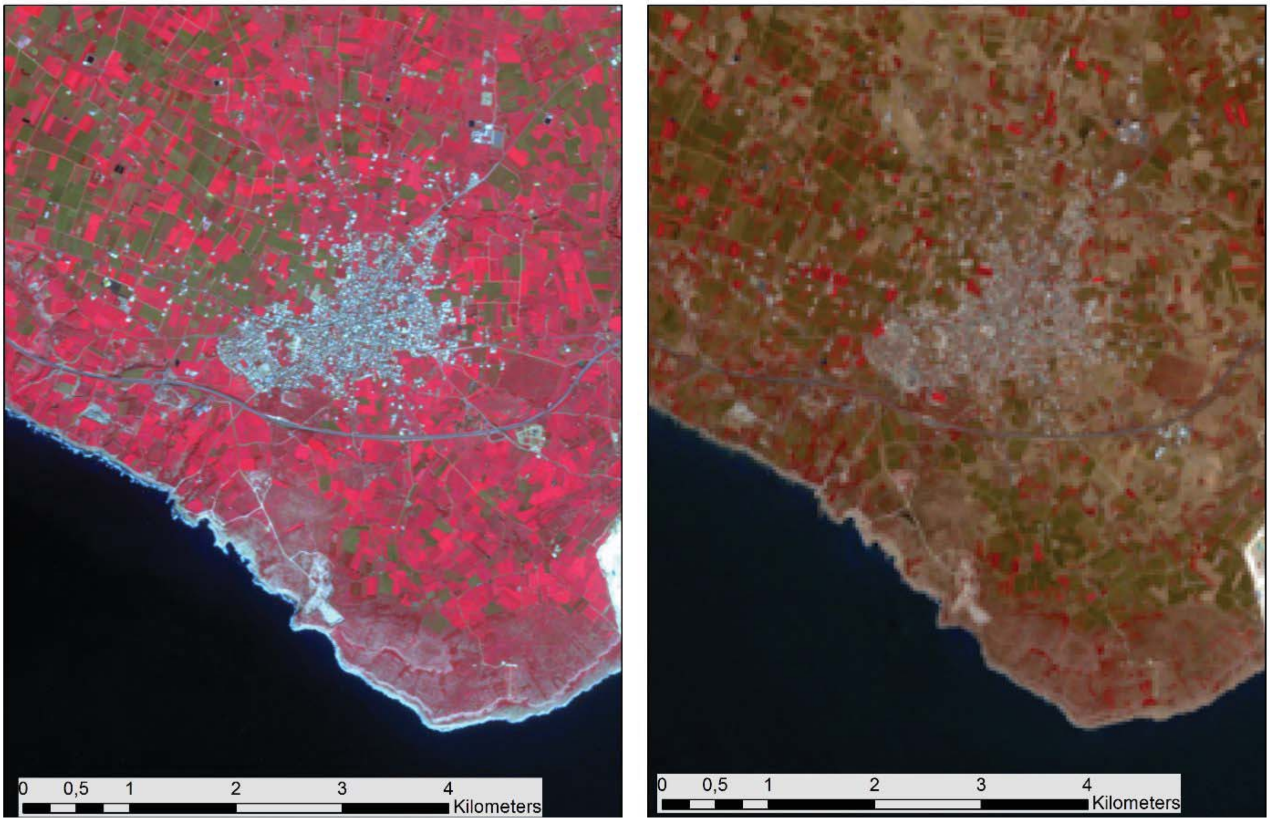

Figure 4: SPOT (left) and Landsat 8 DCM (right) of the western part of Cyprus. The images are shown as NIR-R-G false colour composites.

Sentinel-2 sensor, which started the distribution of satellite data only recently (December 2015) seems to be ideal for the detection of crop marks such as tells. As previous study has demonstrated [18] using simulated data, the spectral range 700 nm - 800 nm (see Figure 1) can be of benefit in detection of Neolithic tells in central Greece. These images are freely distributed from the European Space Agency [19]. However, the spatial resolution of the images (20 meters' pixel size) results insufficient for the detection of smaller archaeological sites.

Spy satellite datasets from CORONA space program are another important source of information. During the operational phase of CORONA between 1960 and 1972, over 800,000 high-resolution images have been acquired. The oldest archive from CORONA images dates back to 1962, a year earlier to the first systematic aerial photography of Cyprus. CORONA images have been used in other areas in order to support archaeological research [20]. Some first studies from the potential use of CORONA images for archaeological research in Cyprus can be found in [17] although it should be mentioned that the quality of the images over Cyprus is relative poor (low SNR) compare to other areas of the world. CORONA were acquired at different spatial resolution, acquisition modes such as stereo etc. depending on the military interest for the area.

4.2 Digital Globes – Inspire Directive

Information related to the observation of landscape can be retrieved from 3D digital globes such as Google Earth©, Bing Maps©, NASA World Wind© etc. These visualizations might be very useful for archaeologists as a starting point of their research since they can provide a synoptic view and also historical records of datasets. An example of the use of these tools is demonstrated in Figure 5, where historical images from Google Earth over the archaeological site of Palaepaphos (Old Paphos) are presented. As seen, new constructions in the western part of the modern village have changed the landscape of the area. It should be mentioned that these images are compressed and therefore possibly spatially down sampled, while their spectral resolution is also limited to the RGB bands. Moreover, the geolocation of the images might vary since these cannot be considered as geometrically corrected images.

Figure 5: Google Earth images over the archaeological site of Palaepaphos. Three different snapshots from the 3D engine indicate the different phases of modern construction in the area (images from Google Earth ©).

Recently (15th of January 2016) the Department of Land and Surveyor of Cyprus has launched the Inspire geoportal [21]. The geocatalog (Figure 6), is freely accessible providing some important vector datasets from a variety of governmental authorities of Cyprus to the end users. According to [22], "*this new e-service can be searched based on the metadata that have been prepared, they can be viewed, they can be downloaded and most importantly, they can be directly accessed by any GIS system or any other relevant application, and can be inter-related with other existing geospatial datasets of the users*". These data follow the standards of the Inspire Directive (Directive 2007/2/EC).

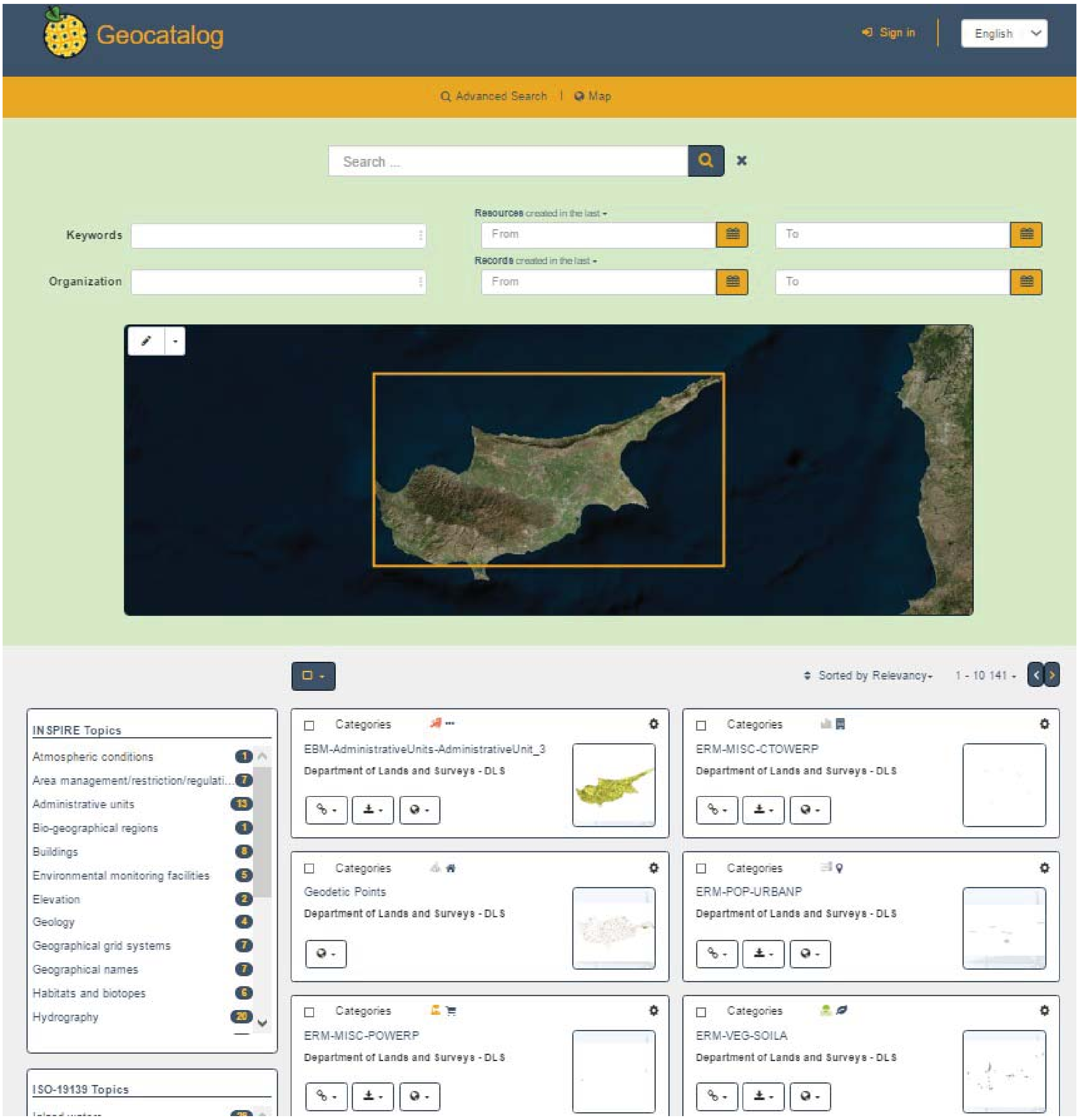

Figure 6: Cyprus Inspire Geoportal [21]

5. DISCUSSION

Archive information in terms of aerial images, satellite products and cadastral maps are undoubtedly useful for archaeologists in order to track significant changes occurred in landscape level and therefore better understand, interpret and rationalize their findings in a field scale. This paper presented a synoptic catalogue of some of the most important datasets that can be used for the island of Cyprus, their strength and weak aspects, their search source etc. Aim of the paper is to elucidate archaeological community operating in Cyprus for a resource information usually left aside from their research mainly due to lack of knowledge on what can be requested, from where, how can be used and what is more suitable for each case study. Additionally, this effort aims to give an impetus to the archaeologists to integrate such information sources into their research, as well as to give them an orientation on where to search for such data.

6. ACKNOWLEDGEMENTS

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AUTOMATIC DAMAGE DETECTION FOR SENSITIVE CULTURAL HERITAGE SITES

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KEY WORDS: Cultural heritage, change detection

ABSTRACT:

The intentional damages to local Cultural Heritage sites carried out in recent months by the Islamic State (IS) have received wide coverage from the media worldwide. Earth Observation data is an important tool to assess these damages in such non-accessible areas: If a fast response is desired, automated image processing techniques would be needed to speed up the analysis. This paper shows the first results of applying fast and robust change detection techniques to sensitive areas. A map highlighting potentially damaged buildings is derived, which could help experts at timely assessing the damages to the Cultural Heritage sites in the observed images.

1. INTRODUCTION

The significance of remote sensing in "exploration, identification and documentation and in monitoring archaeological heritage in the living landscape" has been vigorously highlighted during the 11th *Europae Archaeologiae Consilium* Heritage Management Symposium in 2010 (Cowley, 2011). Remote sensing applications for the aforementioned purposes bear a twofold utility, since from one hand they consist in distant non-destructive techniques and on the other hand they cover broader areas at the same time, moving from the monument level to that of landscape coverage.

When the Islamic State (IS) was rumored in the media to have destroyed cultural heritage sites in Iraq and Syria – Nimrud and Palmyra – officials could not reach the areas in person to confirm the damage. Therefore, the European Space Imaging (EUSI) supplied the Orient Department of the German Archaeological Institute (DAI) very high resolution (VHR) imagery to safely assess the situation on the ground. The images have been processed and analyzed by remote sensing experts of the German Aerospace Center (DLR). A visual analysis confirmed the destruction of several sites as claimed by the IS, such as the temple of Bel and several ancient tower tombs within Palmyra's Valley of the Tombs (UNESCO, 1972).

If change detection for damage assessment is performed by visual analysis on large areas, it becomes a difficult and time-consuming activity, and the knowledge acquired from its results could be incomplete. In the specific, damaged areas could remain undetected for an observer, if the time available for the analysis is limited.

In this paper we propose to apply a change detection algorithm to solve this problem, automatically deriving maps in which the areas suspected of having suffered damages are highlighted. We choose a robust detector in order to obtain a reliable change map if the images present co-registration errors or geometric distortions caused by different acquisition angles. The spots presenting the highest changes are highlighted to rapidly provide a potential set of sensitive areas on which a more detailed analysis should be carried out.

The paper is structured as follows. Section 2 introduces the archeological site of Palmyra and some of the relevant monuments which suffered damages from terrorist activities. Section 3 reports the adopted change detection workflow, while experimental results are described in Section 4. We conclude in Section 5.

2. CASE STUDY

The present paper focuses on a part of the large archaeological site of Palmyra situated in the Syrian Desert north-east of Damascus. The archaeological vestiges of the ancient Roman city are listed in the UNESCO World Heritage since 1980, while from 2013 until today the site has been added to the List of World Heritage in Danger (Article 11 (4) of the World Heritage Convention) (UNESCO, 1972). The monumental ruins belong to an ancient city flourished between the 1st and 3rd century A.D., as part of the Roman Empire. Due to its geographical position, Palmyra was during antiquity a major trading center and bridging route between Mediterranean and Euphrates.

Amongst the first archaeological excavation missions undertaken in the area were the monuments under consideration in this paper, namely the Sanctuary of Bel (Starcky and Munajjed, 1960; Seyrig, 1936). The Temple of Bel is situated in the south-eastern part of the walled city. The Temple dates back to the Hellenistic period, and received several architectural modifications throughout the first two centuries A.D. drawing thus the attention of scholars to the multiple architectural details of the monument, alongside its chronological evolution. During the 12th century, its monumental propylaeum entrance was transformed into a fortified bastion. The Temple of Bel most probably comprises the first building of the sanctuary and it is located approximately in its center. From a Palmyrene inscription on the pedestal of the statue we read that Lishamsh

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to whom the statue belonged, has dedicated the Temple of the Gods Bel, Iarhibol and Aglibol in its sanctuaries in 32 A.D. (Cantineu, 1934, UNESCO, 1972). The Semitic's god Bel worship was dominant in the Palmyrene religious cult (Danti, 2001).

Figure 1. Temple of Bel (left) and tower tomb of Elahbel (right). Photos taken by T. Paulette in 2005 and by Wolfe Expedition in 1885, respectively.

Outside the walls of the city its ancient necropolis is to be found. Here under examination is the western necropolis, better known as Valley of the Tombs. This cemetery contains some impressive built tombs belonging to the architectural type of the tower tombs (e.g. Tower tomb of Elahbel, Tower tomb of Atenatan, Tower tomb of Julius Aurelius Bolma, Tower tomb of Kithoth Tomasu). These tombs were erected during the 1st and 2nd centuries A.D. to serve the wealthy inhabitants of the city, and their existence and preservation alongside the study of the burial customs to be detected within the tombs, consist of an important source of information for the lives of the elite class of that time. The tower tombs contained rich decoration such as wall paintings, funerary sculptures, inscriptions, and sarcophagi. Photographic documentation of the described sites is reported in Fig. 1.

3. ROBUST CHANGE DETECTION

The aim of a change detection algorithm is to provide a map of changes when given in input two or more images acquired at different times over the same area. For the applications described in this paper, the desired output should highlight the locations of monuments which suffered damages or changes in a short time span.

Nevertheless, automatic change detection techniques may be difficult to apply in practice. For example, the differences between pre- and post-event images may be difficult to obtain in a reliable way if the acquisition dates of the two images are too far away. Even if this is not the case, a pixel-based analysis is difficult to carry out even after an accurate co-registration step, as often, no high resolution Digital Surface Model (DSM) is available. In this case, images may exhibit orthorectification errors, and the differences in view angle introduce in turn pronounced geometric distortions.

Many approaches have been proposed to solve this problem, such as region-based or grid-based comparison (Blaschke, 2010; Im et al., 2008). For a fast comparison, Robust Difference (RD) has been initially proposed by Castilla et al. (2009) and successfully applied to compare DSMs (Tian et al., 2014). The RD distance is based on the assumption that the corresponding pixels of two images show the minimum intensity value differences within a small region, especially when the images were captured by the same sensor.

A RD between the pre-disaster image X and a post-disaster image Y for a pixel at coordinates (i, j) can be defined as the minimum of differences computed between the pixel $Y(i, j)$ in the post-disaster image and a certain neighborhood (with window size $2w + 1$) of the pixel $X(i, j)$ in the pre-disaster image X. The RD (i, j) relative to the pixel (i, j) are defined as:

$$RD(i, j) = \min_{p,q}\left\{abs(Y(i, j) - X(p, q))\right\} \quad (1),$$

where i, j = image coordinates
w = maximum distance from i, j
$(p, q) \in [i - w, j + w]$ = coordinates of pixels in the neighbourhood centered around i, j

This means that only the minimum value of the absolute difference is taken into account, all within the defined window size, which should be adjusted based on the scale of the occurred changes. Typically used window sizes are square and range from 3×3 up to 11×11 pixels depending on the amount of geometric distortions caused by different acquisition angles and differences between the original spatial resolution of the two available images. As the input images are multispectral, the RDs are computed for each channel separately; subsequently, their chi-distances are summed up to produce the final change map.

The RD is by definition robust to geometric distortions caused by differences in the terrain and to errors introduced in the co-registration step. To produce a final change map, a threshold is applied selecting all pixels with $RD > 1200$. Morphological filtering (opening and closing) is subsequently applied to the binary thresholded image to produce the final results.

4. EXPERIMENTS

Figs. 2 and 3 report the subsets of two WorldView-2 datasets acquired outside the city center of Palmyra, Syria, on the 27th of August and 2nd of September 2015, respectively. Henceforth we refer to these two dates as as t_1 and t_2.

At time t_1 the Islamic State (IS) had already destroyed several Cultural Heritage (CH) sites in the area, namely the tower tombs of Atenaten, Iamliku, and the Banai family, the temple of Baalshamin, and the Abu Behaeddine shrine. Between t_1 and t_2, other tower tombs and the temple of Bel have been damaged. In the figures the temple of Bel is located in the bottom right, while the tower tombs are scattered in the upper left part of the image.

The available images exhibit some pronounced orthorectification errors, as no high resolution Digital Surface Model (DSM) is available. We are therefore in one of the cases for which the RD described in previous section may yield more reliable results.

In a first step the co-registration of the images has been refined by automatically deriving 1000 Ground Control Points by matching of Scale Invariant Feature Transform features (Löwe, 2004) between the two images, and by warping the image acquired at time t_1 using as reference the image acquired at time t_2.

The absolute value of the RD, representing the confidence that a real change has taken place for a given pixel, is reported in Fig. 4. To produce a change map, a thresholded version of the image has undergone a filtering through three cycles of morphological opening and closing. The structuring element of choice was a disc of size 3, corresponding to a 3×3 square window filled with ones, with zeros in the corners.

Results are reported as red areas in Fig. 5. All of the tower tombs in the image destroyed by the IS between t_1 and t_2 are correctly detected from the algorithm, well agreeing with the report on the situation in Palmyra in (Cuneo, 2015). On the right, the destruction of the central part and the eastern wall of the temple of Bel are also detected. The only false alarm is given in the lower central part of the image due to an artifact in the dataset acquired at time t_2 (see Fig. 6).

5. CONCLUSIONS

The importance of remotely sensed earth observation data has been widely acknowledged in recent years. The change detection methodology proposed in this paper is aimed at increasing the timeliness for the production of detailed damage assessment maps in CH sites in sensible areas providing the image analysts with a map of potentially damaged sites. As the process is robust and fast, it would represent a valuable, cost and time efficient tool in the hands of professionals dealing with CH management and monitoring, as important information in sensitive areas could be promptly derived, once the post-change image is available and co-registered to the pre-change acquisition.

The proposed method could be applied in similar cases to inaccessible areas of war conflict in order to obtain a rapid detection and documentation of the damages. Furthermore, the methodology is arguably appropriate for long term monitoring of cultural heritage sites in terms of their inspection against natural and anthropogenic hazards.

The methodological approach here presented could thus be imported in the general planning related to the development of risk-preparedness strategies for cultural heritage sites, as well as for the disaster-response planning. The development of strategy for the protection of CH in the event of armed conflict request regular monitoring and inspection of the condition of significant CH sites, to be undertaken as a basis of follow-up actions further underlining the need for salvage recording or documentation of threaten or damaged cultural property (Stovel, 1998).

In the future, the method could be enhanced by integrating the analysis of texture parameters extracted from the images, as destroyed sites usually appear as areas where high frequencies are predominant.

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Figure 2. Subset of the WorldView-2 image acquired on the 27th of August 2015 (©European Space Imaging / DigitalGlobe).

Figure 3. Subset of the WorldView-2 image acquired on the 2nd of September 2015 (©European Space Imaging / DigitalGlobe).

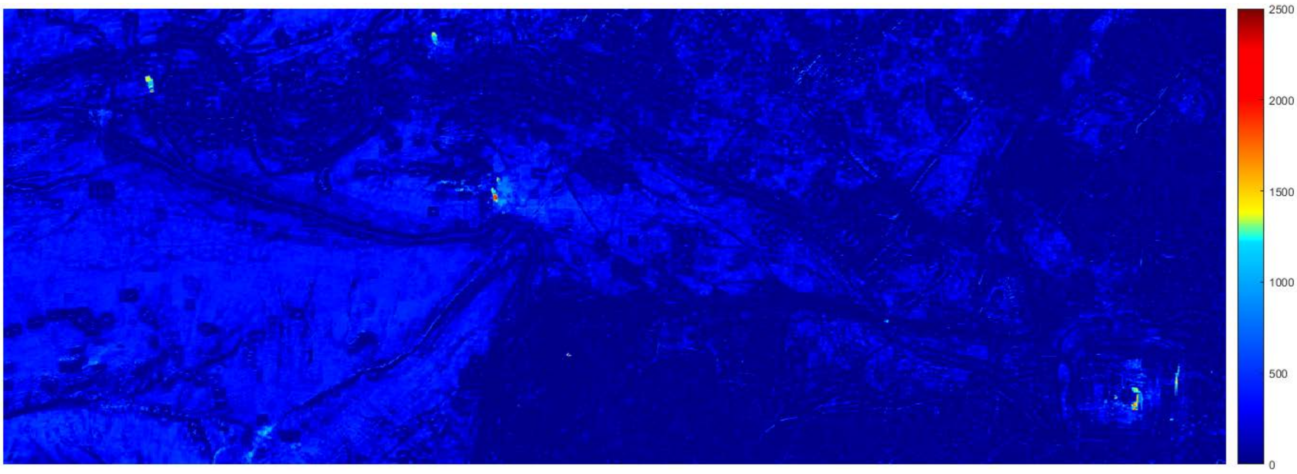

Figure 4. Robust change map

Figure 5. Post-processed change map overlaid on the 2nd of September 2015 WorldView-2 image (©European Space Imaging / DigitalGlobe).

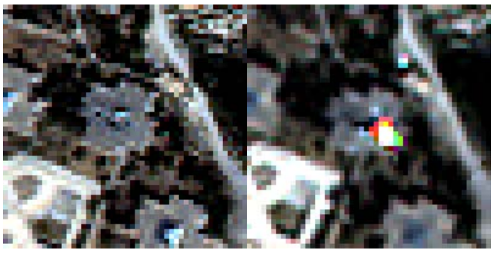

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Figure 6. Figure 5. Image details for the two images related to the only false alarm in the lower center of Fig. 5. This is due to an artefact present in the second image (©European Space Imaging / DigitalGlobe).

ANNEX II

Posters – Abstracts

1. Research and support for knowledge transfer in the ATHENA Twinning project: Remote sensing for cultural heritage, Hadjimitsis D. G., Agapiou A., Lysandrou V., Nisantzi A., Christofe A., Tzouvaras M., Papoutsa C., Mamouri R.-E., Mettas C., Evagorou E., Themistocleous K., Lasaponara R., Masini N., Danese M., Sileo M., Krauss T., Cerra D., Gessner U., Schreier G., GEOBIA 2018, Montpellier, France.
2. The use of Copernicus data to support archeological research in the Eastern Mediterannean, Hadjimitsis D. G., Christofe A., Agapiou A., Nisantzi A., ., Tzouvaras M., Papoutsa C., Mettas C., Evagorou E., Themistocleous K., Lysandrou V., Kouta G., Lasaponara R., Masini N., Schreier G., EARSEL 2018.
3. ATHENA project: training activities for the detection of looted archaeological sites, Hadjimitsis D. G., Christofe A., Agapiou A., Lysandrou V., Themistocleous K., Lasaponara R., Masini N.,Geophysical Research Abstracts, EGU2018, Vienna, Austria.
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Article

Research and support for knowledge transfer in the ATHENA Twinning project: Remote sensing for cultural heritage

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Abstract: This paper presents some of the outcomes of an on-going Horizon 2020 Twinning project, under the acronym ATHENA. The project aims to establish a "Remote Sensing Science Center for Cultural Heritage" in Cyprus. The Center foresees to support the current Cultural Heritage (CH) needs through the systematic exploitation of Earth Observation technologies. For the establishment of the center, the existing Remote Sensing and Geo-Environment Research Laboratory of the Eratosthenes Research Center (ERC) based at the Cyprus University of Technology (CUT), is twinned with internationally-leading counterparts from the EU, the National Research Council of Italy (CNR, through IMAA and IBAM) and the German Aerospace Centre (DLR). Through this network, the ATHENA twinning project strengthens the remote sensing capacity in cultural heritage at CUT's ERC.

A core element within ATHENA is knowledge transfer, achieved primarily through intense training activities (including virtual training courses, workshops and summer schools) with an ultimate scope to enhance the scientific profile of the research staff and to accelerate the development of research capabilities of the ERC, as well as to promote Earth Observation knowledge and best practices intended for CH. Active and passive remote sensing data for archaeology, SAR for change and deformation detection, satellite monitoring for archaeological looting, integration of remote sensing data for protection and preservation of cultural are elaborated in these training activities.

The preservation of CH and landscape is today a strategic priority not only to guarantee cultural treasure and evidences of the human past to future generations, but also to exploit them as a strategic and valuable economic asset. This is an extremely important key factor for the countries which are owners of an extraordinary cultural legacy, that is particularly fragile due to its specific characteristics and specific risks at which CH is continuously exposed. Taking advantage of large-spatial coverage, high-spectral and sensitivity satellite remote sensing can be usefully adopted for contrasting looting. Satellite technologies offer a suitable chance to quantify and analyze this phenomenon, especially in several countries, from Southern America to Middle East, where the onsite surveillance is not much effective or non-practicable due to military or political restrictions. The training activities organized by CNR are focused on the characterization of the looting phenomenon from a multi-faced prospective. The training activities are focused on the use of high spatial resolution satellite and aerial optical images and Lidar acquisition to quantitatively assess looting. An overview of methodologies and data processing for the identification and quantification of looting features (using both single date and multi temporal satellite images and OBIA classifications) are discussed for several study areas.

The project's scope is to position the Centre internationally and stimulate future cooperation through placements at partner institutions and participation at international conferences as well as enhance the research and academic profile of all participants. The scientific strengthening and networking achieved in Cyprus through the ATHENA project could be of great benefit for the entire Eastern Mediterranean Region bearing a plethora of archaeological sites and monuments urgently calling for monitoring and safeguarding.

Keywords: Remote sensing; Cultural Heritage; Cyprus; ATHENA project

The use of Copernicus data to support archeological research in the Eastern Mediterranean

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Based on satellite and in situ observations, the Copernicus services deliver near-real-time data on a global level which can also be used for local and regional needs. The on-going Horizon 2020 "ATHENA" Twinning project uses specific Copernicus data to identify several case studies. "ATHENA" project aims to establish a "Remote Sensing Science Center for Cultural Heritage" in Cyprus. The Center foresees to support the current Cultural Heritage (CH) needs through the systematic exploitation of Earth Observation technologies. For the establishment of the center, the existing Remote Sensing and Geo-Environment Research Laboratory of the Eratosthenes Research Center (ERC) based at the Cyprus University of Technology (CUT), is twinned with internationally-leading counterparts from the EU, the National Research Council of Italy and the German Aerospace Centre (DLR). Through this network, the ATHENA twinning project strengthens the remote sensing capacity in cultural heritage at CUT's ERC.

Within "ATHENA" project, training courses, workshops and other activities are carried out, promoting Earth Observation knowledge and best practices. Earth Observation technologies are introduced, systematically employed, and further developed for Cultural Heritage applications. These technologies implement Copernicus data and services for the preservation of Cultural Heritage as they can be usefully adopted for tackling the looting phenomenon. Satellite technologies offer a suitable chance to quantify and analyze this phenomenon, especially in the region of the Eastern Mediterranean, where the onsite surveillance is not much effective or non-practicable due to military or political restrictions. Also, active and passive remote sensing data for archaeology, SAR for change and deformation detection, satellite monitoring for archaeological looting, integration of remote sensing data for protection and preservation of cultural heritage are also further explored.

The scientific strengthening and networking achieved in Cyprus through the ATHENA project could be of great benefit for the entire Eastern Mediterranean Region bearing a plethora of archaeological sites and monuments urgently calling for monitoring and safeguarding.

Keywords: Cyprus, Eastern Mediterranean, Cultural Heritage, Copernicus, Remote Sensing

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ATHENA project: training activities for the detection of looted archaeological sites

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A core element of the ATHENA Horizon 2020 funded project is knowledge transfer, achieved primarily through intense training activities (including virtual training courses, workshops and summer schools) with an ultimate scope to enhance the scientific profile of the research staff and to accelerate the development of research capabilities of the Eratosthenes Research Centre (ERC), placed in Cyprus. In addition, the project aims to promote Earth Observation knowledge and best practices intended for Cultural Heritage (CH).
The preservation of CH and landscape is today a strategic priority not only to guarantee cultural treasure and evidences of the human past to future generations, but also to exploit them as a strategic and valuable economic asset (Masini & Soldovieri 2016). This is an extremely important key factor for the countries which are owners of an extraordinary cultural legacy, that is particularly fragile due to its specific characteristics and specific risks at which CH is continuously exposed (Brodie et al. 2001). Taking advantage of large-spatial coverage, high-spectral and sensitivity satellite remote sensing can be usefully adopted for contrasting looting. Satellite technologies offer a suitable chance to quantify and analyze this phenomenon, especially in several countries, from Southern America to Middle East (Casana 2015), where the onsite surveillance is not much effective or non-practicable due to military or political restrictions.
Target training activities organized by the National Research Council (CNR, through IMAA and IBAM) are focused on the characterization of the looting phenomenon from a multi-faced prospective. These workshops are focused on the use of high spatial resolution satellite and aerial optical images as well as Lidar and geophysical data to quantitatively assess looting (Lasaponara et al 2014). An overview of methodologies and data processing for the identification and quantification of looting features (using both single date and multi temporal satellite images and object oriented classifications as in Lasaponara et al 2016) are discussed for several study areas.

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Knowledge transfer through the ATHENA Twinning project: Remote sensing for cultural heritage

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The project aims to establish a “Remote Sensing Science Center for Cultural Heritage” in Cyprus. The Center foresees to support the current Cultural Heritage (CH) needs through the systematic exploitation of Earth Observation technologies. For the establishment of the center, the existing Remote Sensing and Geo-Environment Research Laboratory of the Eratosthenes Research Center (ERC) based at the Cyprus University of Technology (CUT), is twinned with internationally-leading counterparts from the EU, the National Research Council of Italy (CNR, through IMAA and IBAM) and the German Aerospace Centre (DLR). Through this network, the ATHENA twinning project strengthens the remote sensing capacity in cultural heritage at CUT’s ERC.

The ATHENA project aim is knowledge transfer, achieved primarily through intense training activities (including virtual training courses, workshops and summer schools) with an ultimate scope to enhance the scientific profile of the research staff and to accelerate the development of research capabilities of the ERC as well as to promote Earth Observation knowledge and best practices intended for Cultural Heritage.

The scientific strengthening and networking achieved in Cyprus through the ATHENA project, could be of great benefit for the entire Eastern Mediterranean Region bearing a plethora of archaeological sites and monuments urgently calling for monitoring and safeguarding.

Earth observation technologies and cultural heritage needs through the "ATHENA TWINNING PROJECT"

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This paper presents the main outcomes of the on-going Horizon 2020 *ATHENA* Twinning project, which aims to establish a “Remote Sensing Science Center for Cultural Heritage” in Cyprus. The Center foresees to support the current cultural heritage needs through the systematic exploitation of earth observation technologies. For the establishment of the center, the existing Remote Sensing and Geo-Environment Research Laboratory- of the Eratosthenes Research Center (ERC) based at the Cyprus University of Technology (CUT), is twinned with internationally-leading counterparts from the EU, the National Research Council of Italy (CNR, through IMAA and IBAM) and the German Aerospace Centre (DLR). Through this networking, the ATHENA twinning project strengthens the remote sensing capacity in cultural heritage at CUT’s ERC.

A core element within ATHENA is knowledge transfer, achieved primarily through intense training activities (including virtual training courses, workshops and summer schools) with an ultimate scope to: enhance the scientific profile of the research staff; to accelerate the development of research capabilities of the ERC as well as to promote earth observation knowledge and best practices intended for Cultural Heritage. Active and passive remote sensing data for archaeology, SAR for change and deformation detection, satellite monitoring for archaeological looting, integration of remote sensing data for protection and preservation of cultural heritage are also presented.

The scientific strengthening and networking achieved in Cyprus through the ATHENA project, could be of great benefit for the entire Eastern Mediterranean Region bearing a plethora of archaeological sites and monuments urgently calling for monitoring and safeguarding.

Keywords: remote sensing, cultural heritage, Cyprus

Exploring the Importance of Monitoring the Fire Risk Index in the vicinity of Cultural Heritage Sites in Cyprus using Sentinel Remote Sensing data

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Keywords: **Cultural Heritage, Fire Risk Index, Copernicus, Sentinel**

Abstract

In June 2016, a wildfire outbreak in the region of Solea, district of Nicosia, Cyprus, resulted in the total loss of 18.5 km^2 of vegetated area. The area accommodates a number of cultural heritage sites, amongst them sites included in the UNESCO list of World Heritage Monuments such as the Churches of "Panagia tis Asinou", in Nikitari and "Panagia tis Podithou" in Galata. The incident proved to be a turning point in the reconsideration of the significance of monitoring the risk posed by fire on Cultural Heritage sites. Earth Observation and Remote Sensing techniques provide an efficient and cost effective way of estimating the parameters behind wildfire outbreaks. With the introduction of the Copernicus Sentinel satellite constellation, the extent to which these parameters can be studied is further enabled with short revisit times and higher resolution sensors. The current study aims to explore the estimation of the likelihood of a fire outbreak in the vicinity of candidate Cultural Heritage sites in Cyprus with the use of Sentinel-2 Multispectral Instrument (MSI) imagery. A number of causative agents such as the class and density of vegetation were derived from Sentinel-2 imagery through the estimation of spectral indices coupled with ancillary topographic information such as elevation, slope and aspect derived from a Digital Terrain Model (DTM). A weighted formula for multicriteria analysis was constructed based on the significance of each factor in fire outbreak. Based on the analysis, a map for each of the candidate sites was created with assigned likelihood of fire which was then validated against an archive data pool of past fire incidences.

Copernicus and Cultural Heritage in the Eastern Mediterranean under the 'ATHENA' Project

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Copernicus European Union Programme aiming at developing European information services based on satellite Earth Observation and in situ (non-space) data, is coordinated and managed by the European Commission. Several Copernicus services are currently provided from the Sentinel satellites and other supporting missions. Sentinel-1 and Sentinel-2 can provide systematic radar and optical data worldwide with a high temporal resolution. This paper focuses on the potential use of these sensors for Cultural Heritage applications, providing in this way valuable information to stakeholders and other end-users as well as the archaeological community. Examples include the exploitation of the satellite products for the detection of damaged archaeological sites in the cities of Palmyra and Nimrud, CH sites in Syria and Iraq, as well as to examine potential soil marks in the UNESCO World Heritage Site of “Nea Paphos” in Cyprus. Looting marks have been based on supporting WorldView-2 products, are also presented. The overall results, expose the potentialities of Earth Observation data and the promising use of the Copernicus Programme as a European service for World Heritage applications. This study was carried out under the H2020 ATHENA project.

From Detection of Underground Archaeological Relics to Monitoring of World Heritage Sites in Danger: Ongoing Research Activities in the Frame of the ATHENA Twinning Project

D. Cerra, A. Agapiou, S. Plank, V. Lysandrou, J. Tian, G. Schreier

Keywords: Archaeology, Remote Sensing, Cultural Heritage, Change Detection, Hyperspectral Imaging

Abstract

The “ATHENA” twinning project aims at establishing a Center of Excellence in the field of Remote Sensing for Archaeology and Cultural Heritage, through a cooperation between the Remote Sensing Research Laboratory at the Cyprus University of Technology (CUT), the Institute of Archaeological and Architectural Heritage of the National Research Council of Italy (IBAM- CNR), and the German Aerospace Centre (DLR). This paper focuses on the joint research carried out in the first year by DLR and CUT. Different achieved results can be ordered chronologically, according to the stage of exploitation for an archaeological site. First of all, a site of archaeological interest must be discovered and defined: to aid in this process, a quantitative ranking of spectral indices to identify buried archaeological relics in hyperspectral images is proposed. Subsequently, information must be catalogued and stored: in the frame of the ATHENA project, efforts have been made to organize the information acquired with a spectrometer in laboratory on mosaics tesserae retrieved in Cyprus in a coherent spectral library. Finally, heritage sites must be constantly monitored, and this could be difficult for non-accessible areas such as conflict zones. For this purpose, the first steps have been made towards the automatic detection of damages to cultural heritage sites from space, based on texture descriptors in remotely sensed images.

EXPLOITATION OF BIG DATA CLOUD INFRASTRUCTURES FOR EARTH OBSERVATION CULTURAL HERITAGE APPLICATIONS: MAPPING THE LAND USE CHANGES PATTERNS IN THE VICINITY OF "THE GREAT PYRAMID AT GIZA"

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KEY WORDS: Earth Observation; Cultural Heritage; Big Data; Google Earth Engine; Land use change; Classification

ABSTRACT: The current availability of the Sentinel images provided in the framework of the Copernicus programme as well as other freely distributed satellite data such as Landsat series may offer further potentials and services for cultural heritage sector. Private and public big data cloud infrastructures have been working in this direction in order to deliver multi-petabyte catalogues of geospatial earth observation datasets for planetary-scale analysis capabilities. In this study, the Earth Engine©, a computing platform which runs using Google's infrastructure, has been exploited in order to map land use changes patterns in the vicinity of "The Great Pyramid at Giza", Egypt, an UNESCO World Heritage site. Multi-temporal radiometric ready calibrated products earth observation datasets have been used for the last two decades, while various advance supervised classification algorithms have been applied. The latest include among other the Random Forest, Fast Naive Bayes, Voting Support Vector Machine (SVM), Margin SVM and GMO Max Entropy classifiers. Training data have been collected and three main classes have been created: urban, soil and vegetation land use types. The classification was applied in a fused annual dataset product, while classification statistics and accuracy assessment was also possible to be performed in the platform. The platform provided almost in real time the classification result. The overall result indicated the dramatic land use change in the western part of the UNESCO World Heritage site, as a result of the urban pressure in the area. Big data engines can be used as a robust platform for earth observation multi-temporal analysis for cultural heritage applications.

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Active Satellite Sensors for the needs of Cultural Heritage: Introducing SAR applications in Cyprus through ATHENA project

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Non-invasive landscape investigation for archaeological purposes includes a wide range of survey techniques, most of which include in-situ methods. In the recent years, a major advance in the non-invasive surveying techniques has been the introduction of active remote sensing technologies. One of such technologies is spaceborne radar, known as Synthetic Aperture Radar (SAR). SAR has proven to be a valuable tool in the analysis of potential archaeological marks and in the systematic cultural heritage site monitoring. With the use of SAR, it is possible to monitor slight variations in vegetation and soil often interpreted as archaeological signs, while radar sensors frequently having penetrating capabilities offering an insight into shallow underground remains.

Radar remote sensing for immovable cultural heritage and archaeological applications has been recently introduced to Cyprus through the currently ongoing ATHENA project. ATHENA project, under the Horizon 2020 programme, aims at building a bridge between research institutions of the low performing Member States and internationally-leading counterparts at EU level, mainly through training workshops and a series of knowledge transfer activities, frequently taking place on the basis of capacity development. The project is formed as the consortium of the Remote Sensing and Geo-Environment Research Laboratory of the Cyprus University of Technology (CUT), the National Research Council of Italy (CNR) and the German Aerospace Centre (DLR).

As part of the project, a number of cultural heritage sites in Cyprus have been studied testing different methodologies involving SAR imagery such as Amplitude Change Detection, Coherence Calculation and fusion techniques. The ATHENA's prospective agenda includes the continuation of the capacity building programme with upcoming training workshops to take place while expanding the knowledge of radar applications on conservation and risk monitoring of cultural heritage sites through SAR Interferometry. The current paper presents some preliminary results from the archaeological site of "Nea Paphos", addressing the potential use of the radar technology.

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Coastal archaeological sites and coastline changes: a multi-temporal GIS study based on aerial and satellite imageries in Cyprus

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Coastal management covers a wide range of topics of which one of the main is relevant to the coastline modification. The current paper presents the preliminary results of a study related to a diachronic observation of coastline changes, achieved through aerial and satellite datasets for the years 1963-2008, integrated to archaeological information. The geographical extension of the investigated area, covers the coastline between Larnaca city and Ayia Napa (S/E Cyprus), which preserves a rich archaeological reservoir. The study places a special effort in mapping the consequent impact of shoreline erosion to the coastal archaeological landscape of Cyprus, as well as understanding the magnitude of the problem along with its evolution in time.

The research was built upon a coastline transition model, while the analysis was calculated using an extension tool named DSAS (Digital Shoreline Analysis System) elaborated in ArcGIS software, provided by the United States Geological Service (USGS). Vector data of historical shoreline positions for the years 1963, 1973, 1993, 2003 and 2008, resulted from the processing of raw data, such as orthophotos and maps as well as high spatial resolution satellite images. These images were processed in order to calculate the annual rates of the coastline diversification for the area under investigation. The overall results of the research highlight the fact that the area under examination, which is rich in archaeological evidence experiences significant erosion problems. In addition, the advantages of integrated GIS tools and aerial – satellite datasets in procedures of coastal zones studies are stressed out.

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ATHENA: Remote Sensing Science Center for Cultural Heritage in Cyprus

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The Cultural Heritage (CH) sector, especially those of monuments and sites has always been facing a number of challenges from environmental pressure, pollution, human intervention from tourism to destruction by terrorism.Within this context, CH professionals are seeking to improve currently used methodologies, in order to better understand, protect and valorise the common European past and common identity.

"ATHENA" H2020-TWINN-2015 project will seek to improve and expand the capabilities of the Cyprus University of Technology, involving professionals dealing with remote sensing technologies for supporting CH sector from the National Research Center of Italy (CNR) and German Aerospace Centre (DLR). The ATHENA centre will be devoted to the development, introduction and systematic use of advanced remote sensing science and technologies in the field of archaeology, built cultural heritage, their multi-temporal analysis and interpretation and the distant monitoring of their natural and anthropogenic environment in the area of Eastern Mediterranean.

Establishing a remote sensing science center in Cyprus: first year of activities of ATHENA project

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Abstract. ATHENA H2020 Twinning project is a three-year duration project and its main objective is to strengthen the Cyprus University of Technology (CUT) Remote Sensing Science and Geo-Environment Research Laboratory in the field of "Remote Sensing Archaeology" by creating a unique link between two internationally-leading research institutions: National Research Council of Italy (CNR) and the German Aerospace Centre (DLR). Through the ATHENA project, CUT's staff research profile and expertise will be raised while S&T capacity of the linked institutions will be enhanced. In this paper the abovementioned objectives are presented through the various activities accomplished in the first year of the project. These activities include both virtual training by experts in topics such as active remote sensing sensors and sophisticated algorithms, as well as scientific workshops dedicated to specific earth observation and cultural heritage aspects. During this first year, outreached activities have been also performed aiming to promote remote sensing and other non-destructive techniques, including geophysics, for monitoring and safeguarding archaeological heritage of Cyprus. The ATHENA center aims to serve the local community of Cyprus, but at the same time to be established in the wider area of eastern Mediterranean.

adfa, p. 1, 2011.

Keywords: Cultural Heritage, Remote Sensing, Cyprus, Center of Excellence

1 Introduction

ATHENA is the acronym of a three-year duration H2020 Twinning 2015 project, entitled "Remote Sensing Science Center for Cultural Heritage" (Proposal number: 691936), initiated at the end of 2015 [1]. Scope of the project is to establish a remote sensing science center in Cyprus for supporting the Cultural Heritage sector, by improving the capabilities of the local personnel involved in the project. National Research Council of Italy (CNR), by means of two institutes IMAA and IBAM, and the German Aerospace Centre (DLR) are acting as the leading research institutions aiming to provide this know-how and expertise through a variety of training activities and dissemination actions.

The project focuses on best practices for monitoring and safeguarding Cultural Heritage based on multidisciplinary collaborations and filling the gap between cross-disciplinary research and exploitation methods through different scientific domains such as history, archaeology, architecture, urban design, sociology, anthropology, engineering, science for conservation, and computer sciences through the use of remote sensing technologies. Such combination of innovative methodologies to enhance the understanding of European Cultural Heritage by means of remote sensing techniques will bring new knowledge, collaboration across disciplines, and social benefits. The innovative procedures [2, 3] and applications will enable remote communication and collaboration across the industry, professionals, experts, researchers and academia. The ATHENA center aims to devote to the introduction, development and systematic use of advanced remote sensing science and technologies in the field of archaeology, built cultural heritage, their multi-temporal analysis and interpretation and the distant monitoring of their natural and anthropogenic environment. As a starting point ATHENA exploits the current capabilities of the Remote Sensing and Geo-Environment Laboratory at the Cyprus University of Technology (CUT), both in terms of capacity as well of equipment, performing advance research and offering support to the CH sector. The Centre will be in close collaboration with both national as well international research institutes and stakeholders, providing integrated remote sensing services and solutions in the area of the Eastern Mediterranean. The new perspectives on archaeological and cultural heritage in the region will position ATHENA as a center of knowledge and a standard lab in the field of Remote Sensing Archaeology. This paper aims to present the overall activities carried out in the first year of the project in different levels: training, dissemination, outreach activities etc. The knowledge acquired during the first year will be used to maximize the impact of future work of the project and to promote the remote sensing capabilities for Cultural Heritage.

2 Overall Strategy

The first year of ATHENA project was built upon a variety of training and outreach activities. The former includes workshops dedicated to specific topics of earth observation and remote sensing technologies, summer schools which were merged with in-situ visits to archaeological sites of Cyprus, researchers exchange between the Remote Sensing and Geo-Environment Lab of CUT and the two leading institutions (CNR and DLR) as well as virtual training courses. Outreach activities included amongst other, presentations to conferences and seminars, publications in scientific journals is the field of remote sensing and/or archaeology/cultural heritage, lecturing at schools, newsletters etc. ATHENA project was also presented to local stakeholders. Both activities aimed to “educate the educators” since remote sensing and earth observation technology is growing very fast, especially in the last decade. This link will enable current researchers working in the CUT to fill the gap between the existing technology used in the archaeological and culture heritage sector and the emerging technology arising in the next few years. In addition, ATHENA project will be exploited to promote in different levels (i.e. end-user, stakeholders, professionals, scientists) earth observation and remote sensing utility for Cultural Heritage.

3 First year of activities

3.1 Training

Virtual Training on Hyperspectral data and algorithms

The virtual training focused on hyperspectral data and algorithms was delivered by DLR using ordinary telecommunication platforms. The one-day training included an introduction to hyperspectral remote sensing followed by a seminar for band selection in hyperspectral datasets. As hyperspectral sensors measure the reflected solar radiation in up to hundreds different spectral bands, in practical applications it is usually desired to reduce the number of dimensions to speed up computations and increase the accuracy of the results.

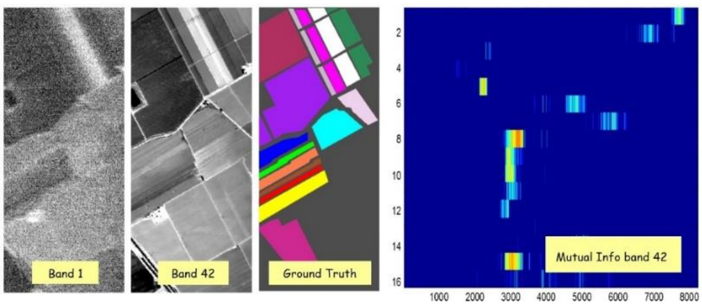

Fig. 1. Mutual information (M.I) for a variety of Bands from the case study of Carnuntum (see more [4])

The lecture included a discussion on statistics, building up to analysis based on mutual information starting from simpler concepts such as variance and Shannon entropy (Fig. 1). The training was concluded by a practical application on the detection of buried structures in an archaeological site in Europe.

Copernicus Workshop

A dedicated workshop for Copernicus entitled “Copernicus contribution to Cultural Heritage”, was organized by DLR during “The Fourth International Conference on Remote Sensing and Geoinformation of Environment” conference held in Cyprus. The workshop was a one-day general introduction to the European Copernicus Earth observation program, focused on topics related to the H2020 ATHENA project: Establish a Center of Excellence in the field of Remote Sensing for Cultural Heritage. The ATHENA twinning partner DLR and guest speakers from European Space Agency (ESA) and the European Commission (EC) introduced the participants to the Copernicus mission and presented various aspects such as: Sentinel space segment; Contributing missions and access to their data; Core and collaborative ground segment; Data policy and access to the data and Core Services targeting those of relevance for ATHENA.

Amongst others, the following general issues have been raised during the discussion: (a) Access to Copernicus Data: The access to Sentinel data will be improved on a European scale by the new initiative of the European Commission to better coordinate and merge core and collaborative data access points. The initiative is name “integrated ground segment” and will start implementation in 2017; (b) There has been a growing interest in the use of satellite observation for monitoring cultural heritage, in particular seen the conflicts in the middle East and the difficulty in assessing damage in-situ; (c) Monitoring of Cultural Heritage - particularly related to damage assessment in conflict zones - is planned to be one of the services accessible through SEA (Support to EU External Actions) as from mid-2016. This is part of the civil security core services of Copernicus. Other actions for the future have been also defined in order to promote the use of remote sensing and earth observation for safeguarding and protection of Cultural Heritage.

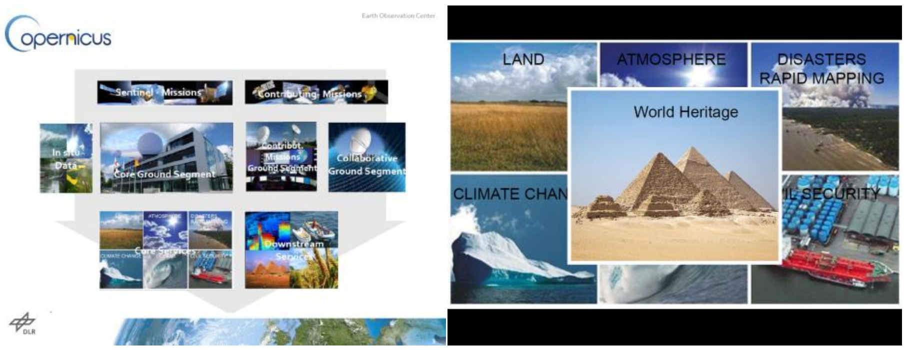

Fig. 2. Screenshots from the lectures given by DLR, presenting the use of Copernicus

Staff exchanges. Geophysics and Ground technologies

During the first year of the ATHENA project, CUT and CNR members had the opportunity to join, as part of staff exchange activity, a summer school organized by CNR IBAM and IREA, held in Pompeii. The summer school was entitled “Geophysics and Remote Sensing for Archaeology” and included lectures, practical field applications at the archaeological site of Pompeii and processing. The course, provided a unique opportunity for researchers to be familiarized with the basics of data collection, processing and interpretation of geophysical techniques such as Ground Penetrating Radar (GPR), magnetic and Electrical Resistivity Tomography (ERT), as well as other passive and active remote sensing techniques, applied not only for detecting buried remains but also for investigating masonry structures and wall paintings in two important areas of Pompeii in accordance with the Archaeological Superintendence.

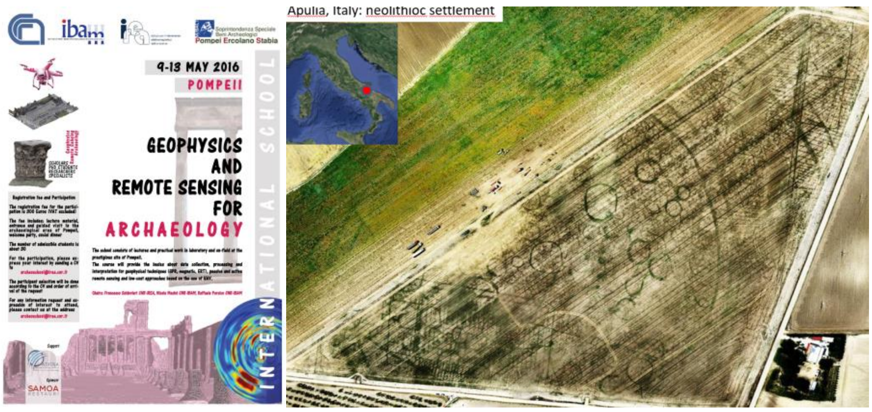

Fig. 3. Leaflet of the Summer School held in Pompeii (left) and example from the lectures given during the school indicating crop marks of a Neolithic settlement in Southern Italy (right)

Synthetic Aperture Radar (SAR) Principles and Applications Summer School

Recent developments in space active remote sensing technologies have been presented during the summer school held in CUT premises by the DLR. The three-day course was focused on the fundamentals of both SAR and interferometric SAR. Targeted examples of interferometry, TerraSAR-X Data, SAR Sentinel-1 Data, ERS-ENVISAT-Data, SAR data availability for Paphos test site (Figure 4) and SAR Data Evaluation were presented. As evidenced during the training, several applications are now possible using SAR data, including oceanography sector, maritime security and ship detection, post-earthquakes, volcanic eruptions and flooding, as well as glaciology, geodesy, urbanization, agriculture and traffic monitoring. Finally, an in-situ visit to the archaeological site under investigation was also carried out.

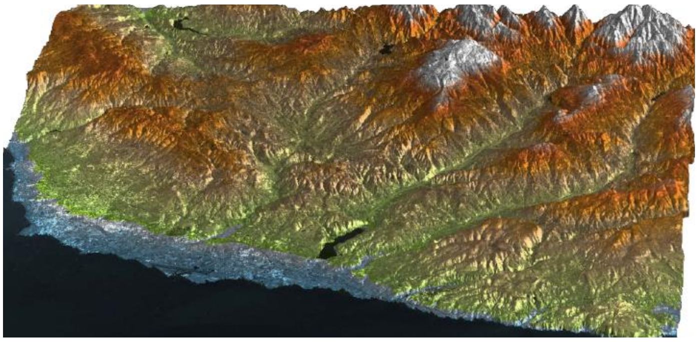

Fig. 4. Example of the TanDEM-X over Paphos district.

3.2 Dissemination

Dissemination activities have been carried out during the first year of ATHENA project. Both posters and conference publications have been published in different events dealing with remote sensing and archaeology such as the SPIE Remote Sensing conference, the Fourth International Conference on Remote Sensing and Geoinformation of the Environment (RSCy2016), the ISPRS Congress, the GEOBIA conference, European Geosciences Union [5], a.o. The presentations were mainly illustrating the objectives of the ATHENA project and evidencing the importance of using remote sensing to support archaeological research and cultural heritage monitoring. Archive aerial and satellite datasets suitable for the case study of Cyprus have been also studied and presented [6] as demonstrated in Figure 5.

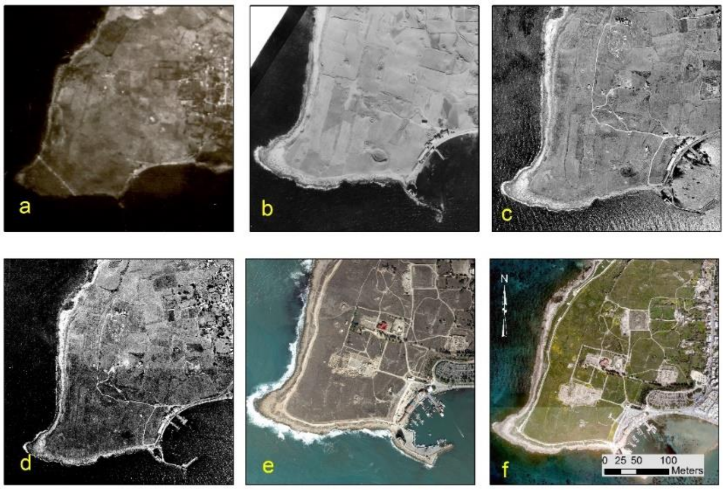

Fig. 5. Aerial images taken over the archaeological site of Nea Paphos: (a) aerial image of Cyprus before the Second World War (b) aerial image of 1945 taken from RAF; (c) aerial image taken in 1962; (d) aerial image of 1993; (e) aerial orthophoto of 2008 and (f) aerial orthophoto of 2014

Moreover, journal publications have been completed including the “Towards a spectral library of Roman to Early Christian Cypriot floor mosaics” [7]. The paper deals with the creation of a spectral library (see Figure 6) in the range of 400-2500 nm for discrimination analysis of materials coming from ancient floor mosaics evaluated with linear constrained un-mixing techniques. The results were found very promising indicating that ground spectroscopy may be used for detection of dominant materials in floor mosaics tesserae.

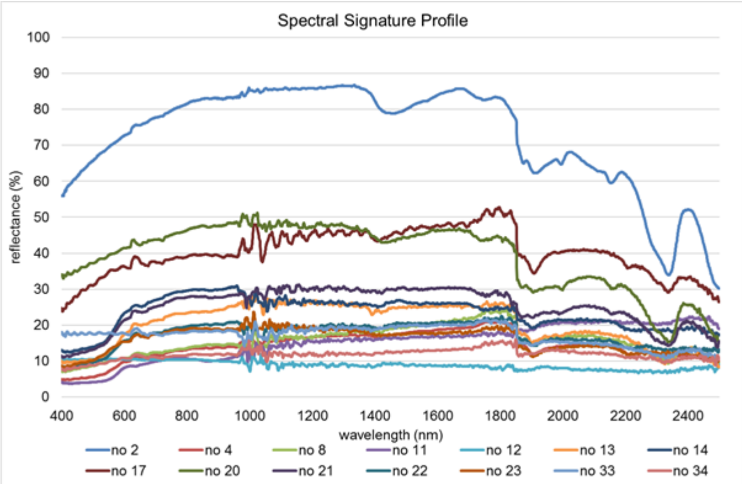

Fig. 6. Example of spectral signature profiles taken from the samples of floor mosaics acquired in the range of 350-2500 nm [8]

3.3 Outreach activities

Educational activities during the Researchers’ Night in Cyprus took place, demonstrating to participants of different ages the potential use of remote sensing to archaeology and the overall aims of the ATHENA project. In addition, lectures were given to undergraduate and postgraduate students of the Department of Civil Engineering and Geomatics of the CUT informing them about the running project and at the same time offering them the opportunity to learn about these new capabilities of Remote Sensing applications. Dissemination activities included the issuing of informational leaflets and press release in local newspapers. The most important events of ATHENA are also presented in the projects’ website, which is continuously updated. At the website, informational and educational material can be downloaded, while a mailing list is kept to inform the users and other researchers regarding the progress of the project.

4 Conclusion

ATHENA project aims to establish a remote sensing science center in the areas of Cultural Heritage and Archaeology. To do so, a variety of actions including training, dissemination and outreach activities have been performed during the first year of the project. The paper aimed to present some of the most important events carried out during this first year. Future actions and activities are currently planned by the consortium partners aiming at the promotion of the center.

Acknowledgements

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ESTABLISHMENT OF A CENTER OF EXCELLENCE IN THE FIELD OF REMOTE SENSING FOR CULTURAL HERITAGE AT THE CYPRUS UNIVERSITY OF TECHNOLOGY: THE 'ATHENA' HORIZON 2020 TWINNING PROJECT

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KEY WORDS: Cultural Heritage, Remote Sensing, Cyprus, Center of Excellence

ABSTRACT: This paper presents an overview of the "ATHENA" project which aims to establish a Center of Excellence in the field of Remote Sensing for Cultural Heritage in the areas of Archaeology and Cultural Heritage through the development of an enhanced knowledge base and innovative methods. This center will be established by twinning the existing Remote Sensing and Geo-environment Research Laboratory at the Cyprus University of Technology (CUT) with internationally-leading counterparts from other Member States of the EU, such as the Institute of Archaeological and Monumental Heritage (IBAM) and Institute of Methodologies for Environmental Analysis (IMAA) of the National Research Council of Italy (CNR) and the German Aerospace Centre (DLR). The goals of the Center will be aligned with the Smart Specialization Strategy of Cyprus and to the new European Cohesion Policy. The close collaboration between CUT and other experts in the field of Remote Sensing for Cultural Heritage in the EU will form a synergic network that will permit the transfer of knowledge and training of the existing personnel of CUT. As a result, the ATHENA project will have both direct and indirect social, scientific, and economic outcomes. In addition, the implementation of the project will facilitate future collaborations with experts of the Archaeology and Cultural Heritage sector in an EU level and in the region, increase the Centers' research capabilities, as well as enhance the research and academic profile of all participants. It is noteworthy to underline the importance of the geographical position of the Center in the region of eastern Mediterranean, a region inhabited thousands of years before and therefore abound in archaeological residues.

Educational Activities of Remote Sensing Archaeology

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ABSTRACT

Remote sensing science is increasingly being used to support archaeological and cultural heritage research in various ways. Satellite sensors either passive or active are currently used in a systematic basis to detect buried archaeological remains and to systematic monitor tangible heritage. In addition, airborne and low altitude systems are being used for documentation purposes. Ground surveys using remote sensing tools such as spectroradiometers and ground penetrating radars can detect variations of vegetation and soil respectively, which are linked to the presence of underground archaeological features.
Education activities and training of remote sensing archaeology to young people is characterized of highly importance. Specific remote sensing tools relevant for archaeological research can be developed including web tools, small libraries, interactive learning games etc. These tools can be then combined and aligned with archaeology and cultural heritage. This can be achieved by presenting historical and pre-historical records, excavated sites or even artifacts under a “remote sensing” approach. Using such non-form educational approach, the students can be involved, ask, read, and seek to learn more about remote sensing and of course to learn about history.
The paper aims to present a modern didactical concept and some examples of practical implementation of remote sensing archaeology in secondary schools in Cyprus. The idea was built upon an ongoing project (ATHENA) focused on the sue of remote sensing for archaeological research in Cyprus. Through H2020 ATHENA project, the Remote Sensing Science and Geo-Environment Research Laboratory at the Cyprus University of Technology (CUT), with the support of the National Research Council of Italy (CNR) and the German Aerospace Centre (DLR) aims to enhance its performance in all these new technologies.

Keywords: remote sensing archaeology; education; Cyprus; ATHENA

ORTHOGONAL EQUATIONS FOR THE DETECTION OF ARCHAEOLOGICAL TRACES DE-MYSTIFIED

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KEY WORDS: Orthogonal equations; Crop Marks; Multispectral Satellite data; Archaeology

ABSTRACT: Orthogonal equations for the enhancement and detection of crop marks using multispectral satellite data have been recently proposed in the literature. Crop marks have been widely used within archaeological research as a proxy to detect buried archaeological remains. Such crop marks can be detected using multispectral remote sensing data and image analysis techniques.

The proposed equations are linear transformations of the initial spectral bands of multispectral datasets. For the calculation of the n-space coefficients of this linear transformation a four-step methodology was followed, separately for each sensor. This paper aims to provide the fundamental concept of the development of these equations as well as some aspects related with the application and accuracy assessment. Spectral characteristics of the sensor, atmospheric effects, and spectral calibration of the datasets as well as the selection of the appropriate period for applying these equations for the enhancements of crop marks are also discussed. Such orthogonal equations may be further developed any applied for any kind of sensor either hyperspectral or multispectral.