# Investigating the Past Using Remote Sensing Techniques

Kyriacos Themistocleous*[ab], Andreas Anayiotos[a,b]
[a]Cyprus University of Technology, Archiepiskopou Kyprianou 30, 3036 Limassol 3036 Cyprus;
[b]ERATOSTHENES Centre of Excellence, 2-8 Saripolou, 3036 Limassol, Cyprus.

**ABSTRACT**

This study will document the abandoned Carmelite monastery located in Polemidia, Limassol District, Cyprus. The monastery was abandoned in 1570 and recently restored by the Greek Orthodox Church, with the name of Panagia Karmiotissa. The church of Panagia Karmiotissa is the only preserved Gothic church in the Limassol area during the time of the Frankish House of Lusignan in Cyprus. To the north area of the church there is a spring, where legend states that a holy shrine of the Virgin Mary springs miraculously. In between the Church and the spring, the rubble of a separate construct is visible, which may possibly be the monk residence halls. From the end of the 12th century to the 19th century, little is known about the site. This study investigates and documents both the church and the surrounding area, using remote sensing data, aerial images and ground penetrating radar. This investigation using remote sensing techniques is an effort to uncover and understand the history of the site.

**Keywords:** Remote Sensing, Cultural Heritage, ecclesiastical monuments, monasteries, Cyprus

## 1. INTRODUCTION

Innovative digital applications in the field of protection and enhancement of cultural heritage, as well as the threats to archaeological and cultural remnants of the past, create important, innovative requirements and challenges of protecting cultural wealth of a country. Digital techniques using UAV and photogrammetry can document and provide data on cultural heritage sites to enhance understanding of their changes over time [1]. The documentation of cultural heritage using UAVs and photogrammetry is becoming a common method to digitize and document cultural heritage monuments, as compared to traditional methods of acquiring 3D models such as laser scanning and LIDAR. Photogrammetry using UAV images provides continuous covering of the object in a high-resolution context, producing a highly dense and textured 3D point cloud model [2-3]. This paper provides the methodology that was used to document the Church of Panagia Karmiotissa at the site of the abandoned Carmelite monastery located in Limassol, Cyprus. In the effort to investigate the history of the area and potential conservation and preservation of the monastery area, within the auspices of the Eratosthenes Centre of Excellence, an extensive survey and documentation of the church and surrounding area was performed. The area was surveyed using Unmanned Aerial Vehicles and a digital 3D photogrammetric model of the church was generated in order to investigate the structure by producing detailed drawings. Thermal imaging was also used to investigate any possible anomalies. Ground penetrating radar was used to conduct a geophysical survey around and inside the church. As well, historical data, aerial photos, temporal satellite images and historical survey maps from the Lands and Surveys Department were collected and imported into a GIS database for further analysis.

## 2. STUDY AREA AND DOCUMENTATION

### 2.1 Study area

The Carmelite monastery in the Limassol region in Polemidia was established, according to different sources, anytime between the middle of the 13th century A.D. to the start of the 14th century A.D [1-5]. The monastery was likely abandoned in 1570, following the Ottoman Invasion. Today, only the church exists, which was restored by the Department of Antiquities in 2001 following a fire, with the name of Panagia Karmiotissa. To the north area of the church there is a cave, where legend states that a holy shrine of the Virgin Mary springs miraculously. On the north side of the church are the ruins of the monastery complex are reduced to heaps of stones. The church of Panagia Karmiotissa is the only preserved Gothic church in the Limassol area during the time of the Frankish House of Lusignan in Cyprus.

*k.themistocleous@cut.ac.cy

The Ruined Carmelite Church and Monastery have been declared as an ancient monument by the Antiquities Department.

Figure 1. Church of Panagia Karmiotissa

The Carmelite monastery church was erected in strict Gothic forms without any structural adornment with a rectangular single nave with a straight choir closure and illuminated by a few lancet windows. Detailed descriptions of the church come from the art historians Enlart [6] and Jeffery [7], who were able to examine the remains of a narthex on the west side of the monastery church around the end of the 1800s and provided a detailed description of the church. The church consists of a simple rectangular envelope built in irregular courses of roughly shaped stones with rubble injected in the joints The Church is built in the single-aisle basilica style, with a pointed, arched roof reinforced in the middle with a pointed bow and Gothic architecture elements. The dimensions of the church are 16.20 meters long and 5.50 wide [6]. The monastery church was erected in Gothic form with a rectangular single nave with a straight choir closure and a few lancet windows. It can only be identified as a Greek Orthodox Church as a result of the addition Greek Orthodox iconostasis.

### 2.2 Documentation process and methodology

Two surveys were completed to document the site of the Carmelite monastery as well as the Church of Panagia Karmiotissa. The first documentation process provided a survey of the entire area, beginning with the placement of 30 ground control points (GCPs) in different areas of the site. The GCPs were distributed evenly around the site in order to geo-reference to create a centimeter accuracy ortho-image. An Unmanned Aerial Vehicle (UAV) with a 1-inch CMOS and 20MP camera was used in order to take images of the church. The survey area coverage was approximately 1km$^2$. The UAV flew at an altitude of 86.9 meters and acquired 723 aerial images to be processed using Structure for Motion (SfM) photogrammetry method. Ground penetrating radar was used to detect any structures below ground.

The second documentation process includes a survey of the Church of Panagia Karmiotissa, beginning with the placement of 50 GCPs inside and outside of the church. The GCPs were used to achieve centimeter accuracy of the model, in order to geo-reference the 3D models, so that they can be overlaid and provide a detailed model of the church using the point clouds generated from RGB imagery. A DJI Mavic 2 Pro UAV with a 20MP.Hasselblad L1D-20c camera was used to generate images of the exterior of the church. A hand-held RGB Canon EOSM3 camera with 24.2 MP CMOS (APS-C) sensor and an EF-M22mm f/2 STM lens was used in a time-lapse function to document the church in the interior in order to create a complete point cloud of the entire structure. For the interior images, multiple portable lighting sources with diffused lighting was used in order to illuminate the interior of the church. As well, the camera was held by a 3D axis hand-held gimbal in order to stabilize the camera and avoid any blurry images as a result of the low lighting in the interior of the church. The total number of images from both the UAV and the RGB camera were 1,438 images. A FLIR thermal camera was used to identify any differences in temperature on the walls of the church. Structure for Motion (SfM) photogrammetry software was used to generate a point cloud of the church from the RGB and multispectral images using the GCPs to geo-reference the models. Finally, the point cloud model was generated, thereby providing an accurate documentation of the church.

The photogrammetric survey was conducted using aerial imagery, which was created from processing the aerial images taken with the UAV into 3D points clouds, 3D surfaces and ortho-photos. Research indicates that UAV images combined with SfM photogrammetry are capable in delivering very high spatial resolution maps usable for the identification and characterization of sensitive coastal marine habitats. The Structure from Motion (SfM) photogrammetry tool was used, which enables 3D reconstruction of the area of interest by generating good quality meshes from images in a semi-automatic way. The software analyses the dataset, detecting geometrical patterns in order to reconstruct the virtual positions of the cameras that were used in order to align the images, including building a sparse point cloud. Structure for Motion (SfM) photogrammetry software was used to generate a point cloud of the church from the aerial images using the GCPs to geo-reference the models resulting in an ortho-photo that provided an accurate documentation of the area.

## 2.3 UAV mapping

During the last years the use of UAVs for aerial surveys is becoming a consolidated application, commonly used for obtaining 3D models of the outer side of buildings [8]. UAVs can be used as a precise, automated and computer-controlled data acquisition and measurement platform, as a result of low-cost sensors such as off-the-shelf digital cameras, GPS/INS (Global Positioning System / Inertial Navigation System) based stabilization and navigation units [9]. In the cultural heritage area UAV applications are mainly focused on documentation, observation, monitoring, mapping, 3D modelling and 3D reconstruction [10] as well as digital maps, digital orthophoto, digital elevation model (DEM) and digital surface models (DSM) [11]. UAV aerial imagery in combination with photogrammetry are emerging technologies providing an innovative approach to 3D documentation of cultural heritage [9].

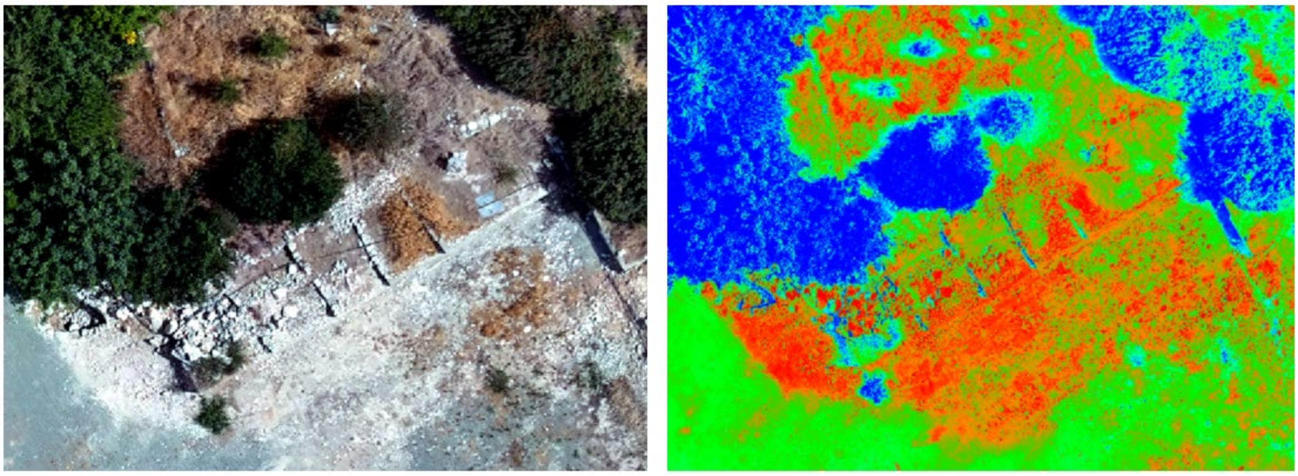

Fig. 2 Remains of monk cells north of the Church.
Left: RGB UAV image Right: Green-Red Index of the UAV image

## 2.4 Photogrammetry

Recent developments in photogrammetry technology provide a simple and cost-effective method of generating relatively accurate 3D models from 2D images [12-14]. Photogrammetry is a precise 3D measurement technique based on the triangulation of several high-quality images that allow for the collection of semantic and spatial data of a building or object. The main outputs of photogrammetric surveys, which are created from stitching and processing hundreds or thousands of images are 3D points clouds, 3D surfaces, ortho-photos and Digital Elevation Models. Several widely used commercial software are available in order to obtain 3D reconstructions of such buildings from images acquired by UAVs [15-17]. These tools, usually based on the Structure from Motion (SfM) approach, enables 3D reconstruction with camera manual or automatic calibration. The introduction of GNSS measurements in the photogrammetric reconstruction procedure, corresponding to the camera locations during image acquisitions, reduces the error level. The software implements image orientation and mesh generation through SfM and dense multi-view stereo-matching algorithms [19]. The first step in the program's procedure is SFM, which is a valuable tool for generating good quality meshes from images in a semi-automatic way. At this stage the software analyses the dataset, detecting geometrical patterns in order to reconstruct the virtual positions of the cameras that were used in order to align the images, including building a sparse point cloud [20].

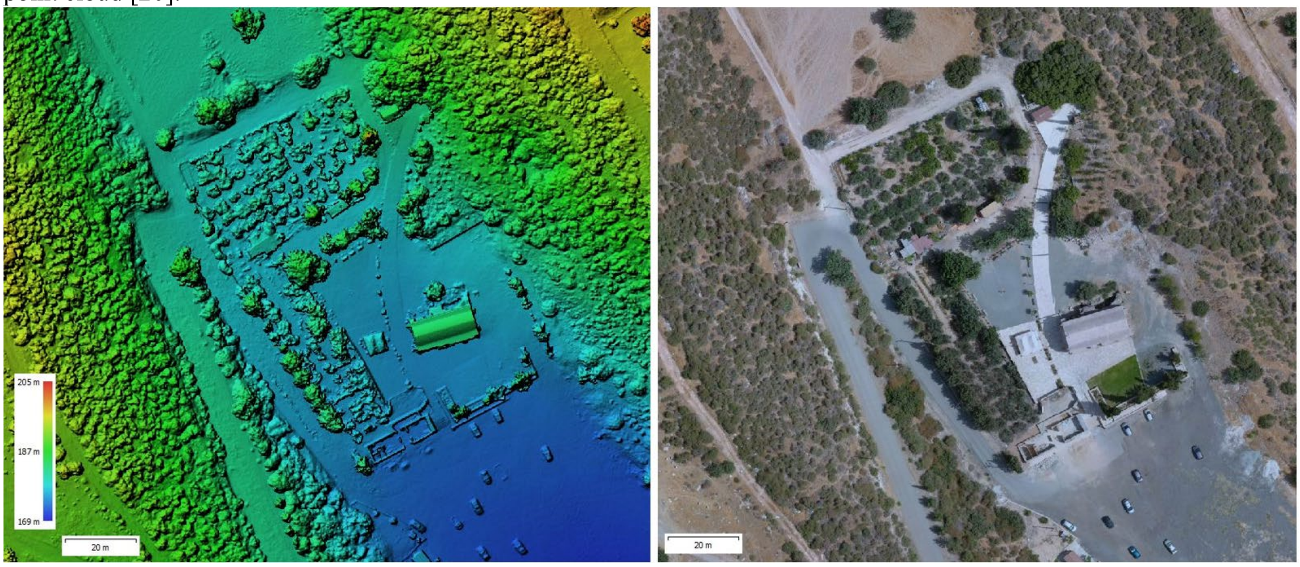


Figure 3: Left: Digital Elevation Model of the Carmelite Monastery site; Right: Carmelite Monastery Site

Digital photogrammetry is a more flexible technique that provides better results in terms of appearance (texture) of the 3D models in less time, due to the higher resolution of the images employed to compute the model texture, compared to the panoramic ones normally used to texturize the laser scanner clouds. In addition, the points composing the clouds obtained with image matching based algorithms are usually colored by reading and averaging the RGB values of the pixels that generate the specific point of the cloud [21]. When combined with UAV images, it is quite easy to generate and complete a 3D model of the structure.

# 3. RESULTS

The documentation of the Church of the Panagia Karmeliotissa was processed using SfM software. Figure 4 shows the overall 3D model that was created of the Church.

Fig. 4: 3D model of the Church

Figure 5 provides the elevation from the four sides of the Church, as resulting from the 3D model.

Fig. 5. Elevations of the Church of Panagia Karmiotissa, as taken from the front, back and sides of the Church.

Figure 6 provides an image of the inside of the church, both from the front entrance and as seen from the side. As the Church is originally Latin, an iconostasis was added to the back of the Church, so that it can operate as an Orthodox Christian Church.

Fig. 6. Interior of Church. Left: Image from front of Church. Right: Image from side section of the Church.

## 4. CONCLUSIONS

The site of the Carmelite monastery, abandoned for several centuries, needs to be further investigated to uncover and present its cultural history and heritage. While the Church of Panagia Karmiotissa has recently been renovated, little is known about the history of the site. Remote sensing techniques, such as UAVs, photogrammetry, thermal imaging and ground penetrating radar was used to gain insight into the site. Preliminary surveys of the area in conjunction with photogrammetry were used to create 3D models and digital elevation models to document and preserve the cultural history of the site. These models combined with specific and precise historical and archaeological information are expected to provide more evidence to uncover and document the full function and operation of the Carmelite monastery and surrounding area and its pan-European history and cultural heritage.

## ACKNOWLEDGEMENTS

The authors would like to acknowledge the 'EXCELSIOR' H2020 Teaming project (www.excelsior2020.eu). This paper is under the auspices of the activities of the 'ERATOSTHENES: Excellence Research Centre for Earth Surveillance and Space-Based Monitoring of the Environment'—'EXCELSIOR' project that has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 857510 and from the Government of the Republic of Cyprus through the Directorate General for the European Programmes, Coordination, and Development.

## REFERENCES

[1] Olympios M, "Rummaging through Ruins: Architecture in Limassol in the Lusignan and Venetian Periods," in Lemesos. A History of Limassol in Cyprus from Antiquity to the Ottoman Conquest, 362–500 (2015)
[2] Church of Panagias Karmiotissas (Kato Polemidia), 5 March, 2021, https://allaboutlimassol.com/en/church-of-panagias-karmiotissas-kato-polemidia
[3] Nicolaou-Konnari A, and Schabel C, "A History of Limassol in Cyprus from Antiquity to the Ottoman Period" Lemesos
[4] Jotischky A, "The Carmelite Order and Greek Orthodox Monasticism- A Study in retrospective Unity"
[5] Church of Panagia Karmiotissa, The church of legend and tradition, 5 March, 2021, https://www.cyprusalive.com/en/church-of-panagia-karmiotissa)).
[6] Enlart C, [Gothic Art and the Renaissance in Cyprus], trans. David Hunt, London: Trigraph 246-253 (1987; originally published 1899),.
[7] Jeffery G [A description of the historic monuments of Cyprus. Studies in the archaeology and architecture of the island] (1918)
[8] Masiero, A., Chiabrando, F., Lingua, A. M., Marino, B. G., Fissore, F., Guarnieri, A., and Vettore, A. (2019) 3D Modeling of Girifalco Fortress, Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XLII-2/W9, 473-478, https://doi.org/10.5194/isprs-archives-XLII-2-W9-473-2019, 2019.
[9] Caprioli, Mauro & Mancini, Francesco & Mazzone, Francesco & Scarano, Mario & Trizzino, Rosamaria. (2015). UAV Surveys for Representing and Document the Cultural Heritage. Proceedings of the XIII International Forum, Aversa Capri, 11-13 June, 2015.

[10] Remondino, F., Barazzetti, L., Nex, F., Scaioni, M., Sarazzi, D. (2011). UAV Photogrammetry for Mapping and 3D Modeling-Current Status and Future Perspectives-". International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. XXXVIII-1/C22 UAV-g 2011, Conference on Unmanned Aerial Vehicle in Geomatics, Zurich, Switzerland.
[11] Patias,P., Kaimaris, D., Georgiadis, Ch., Stamnas, A., Antoniadis, D. & Papadimitrakis, D. (2013). 3D Mapping of Cultural Heritage: Special Problems and Best Practices in Extreme Case-Studies". ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume II-5/W1, 2013 XXIV International Cıpa Symposium, 2 – 6 September 2013, Strasbourg, France.;
[12] Themistocleous, K., Agapiou, A., King, H.M., King, N. and Hadjimitsis, D.G. (2014a). More Than a Flight: The Extensive Contributions of UAV Flights to Archaeological Research - The Case Study of Curium Site in Cyprus. Proceedings of the Progress in Cultural Heritage: Documentation, Preservation, and Protection. 5th International Conference, EuroMed 2014, Limassol, Cyprus. Springer LNCS 8740, EuroMed2014 Conference, 396-409.
[13] Themistocleous K. & Danezis, C. (2019). Monitoring Cultural Heritage Sites Affected by Geo-Hazards Using In- Situ and SAR Data: The Choirokoitia Case Study. Remote Sensing for Archaeology and Cultural Landscapes- Best practices and perspectives across Europe and Middle East, Springer Press. Print ISBN: 978-3-030-10978-3, Electronic ISBN: 978-3-030-10979-0
[14] Themistocleous, K., Ioannides, M., Agapiou, A., Hadjimitsis, D.G. (2015b). The Methodology Of Documenting Cultural Heritage Sites Using Photogrammetry, UAV And 3D Printing Techniques: The Case Study Of Asinou Church In Cyprus. In: Proceedings of the Third International Conference on Remote Sensing and Geoinformation of Environment, 16-19 March, 2015.
[15] Gonzalez-Aguilera, D., L´opez-Fern´andez, L., Rodriguez-Gonzalvez, P., Hernandez-Lopez, D., Guerrero, D., Remondino, F., Menna, F., Nocerino, E., Toschi, I., Ballabeni, A. et al., 2018. GRAPHOS–open-source software for photogrammetric applica-tions. The Photogrammetric Record 33(161), pp. 11–29.
[16] Vosselman, G., Gorte, B. G., Sithole, G. and Rabbani, T., 2004. Recognising structure in laser scanner point clouds. ISPRS - In-ternational archives of photogrammetry, remote sensing and spa-tial information sciences 46(8), pp. 33–38.
[17] Rabbani, T., Van Den Heuvel, F. and Vosselmann, G., 2006. Seg-mentation of point clouds using smoothness constraint. ISPRS -International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences 36(5), pp. 248–253.
[18] Makuti, S., Nex, F. and Yang, M., 2018. Multi-temporal classifi-cation and change detection using uav images. In: 2018 ISPRS TC II Mid-term Symposium Towards Photogrammetry 2020, 4–7 June 2018, Riva del Garda, Italy, International Society for Pho-togrammetry and Remote Sensing (ISPRS), pp. 651–658.
[19] Russo, M., Guidi, G., Rodriguez Navarro, P., Gonizzi Barsanti, S. & Micoli, L. (2013). Quick textured mesh generation in Cultural Heritage digitization. Conference: Built Heritage 2013 Monitoring Conservation Management, pp. 874-882. ISBN. 978-88-908961-0-1.
[20] Themistocleous K. (2019). The Use of UAVs for Cultural Heritage and Archaeology. Remote Sensing for Archaeology and Cultural Landscapes- Best practices and perspectives across Europe and Middle East, Springer Press. ISBN: 978-3-030-10978-3
[21] Pepe M., Ackermann S., Fregonese L., Achille C. 2016. 3D Point Cloud Model Color Adjustment by Combining Terrestrial Laser Scanner and Close Range Photogrammetry Datasets. World Academy of Science, Engineering and Technology International Journal of Computer and Information Engineering Vol:10, No:11, 2016