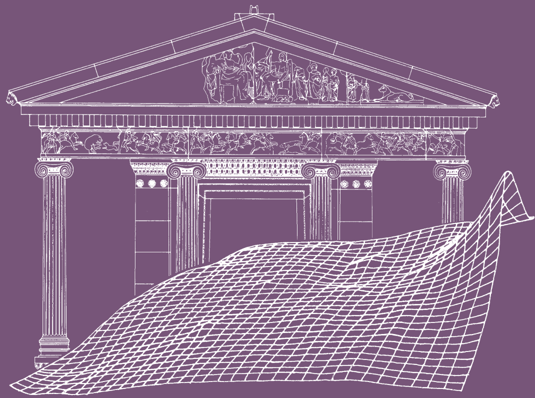

KNOWLEDGE, ANALYSIS AND INNOVATIVE METHODS FOR THE STUDY AND THE DISSEMINATION OF ANCIENT URBAN AREAS

KAINUA
2017

Proceedings of the KAINUA 2017
International Conference in Honour
of Professor Giuseppe Sassatelli's 70th Birthday
(Bologna, 18-21 April 2017)

edited by
Simone Garagnani, Andrea Gaucci

ARCHEOLOGIA E CALCOLATORI
28.2
2017

All'Insegna del Giglio

KNOWLEDGE, ANALYSIS AND INNOVATIVE METHODS FOR THE STUDY AND THE DISSEMINATION OF ANCIENT URBAN AREAS

Proceedings of the KAINUA 2017
International Conference in Honour
of Professor Giuseppe Sassatelli's 70th Birthday
(Bologna, 18-21 April 2017)

edited by
Simone Garagnani, Andrea Gaucci

ARCHEOLOGIA E CALCOLATORI
28.2
2017

All'Insegna del Giglio

Realizzazione grafica della sovracoperta di Marcello Bellisario
Rivista «Archeologia e Calcolatori» (ISSN 1120-6861, e-ISSN 2385-1953)
ISBN 978-88-7814-785-0, e-ISBN 978-88-7814-786-7

Firenze, dicembre 2017
Stampa, Andersen S.p.a.
Abbonamento: € 40,00. Spedizione: Italia, gratuita; estero, a carico del destinatario.

TABLE OF CONTENTS

Archeologia e Calcolatori
28.2, 2017, 469-484

MULTI-TEMPORAL IMAGES AND 3D DENSE MODELS FOR ARCHAEOLOGICAL SITE MONITORING IN HIERAPOLIS OF PHRYGIA (TR)

1. Introduction

The archaeological areas are one of the fields in which the contribution of image-base and range-based Geomatics techniques were employed since long time and are now getting popular (Hadjimitsis *et al.* 2009; Campana 2017). In recent times, Remotely Piloted Aircraft Systems (RPAS), together with Terrestrial Laser Scanning (TLS) survey systems become more and more interesting to be studied in excavations sites for monitoring purposes and solving high detail data and large scale and comprehensive mapping matters both from terrestrial and aerial point of view. 3D information derived from different acquisition campaign and different sensors too, belonging to the same spatial system, can be integrated and create a multi-temporal and multi-scale database (Remondino, Rizzi 2010; Kersten, Lindstaedt 2012; Moussa, Abdel-Wahab, Fritsch 2012; Chiabrando *et al.* 2016; Farella *et al.* 2016). The contribution of multi-sensor acquisitions, as it is known from increasing scientific experiences, offers by now to archaeological studies the possibility to obtain a multi-temporal view of the site with restricted time windows, but it is interesting considering also the possibility of a valuable integration and contribution of older image-based documentation, already stored in archives.

In a complex archaeological area as the one of Hierapolis of Phrygia in Pamukkale (TR), a very interesting site investigated since several tens of years by the MAIER – Italian Archaeological Mission of Hierapolis, the impressive excavations have required extensive and accurate large-scale survey and documentation projects. This paper will also show the evolution over time of 3D survey methods. In particular, the presented experiences regarding the documentation campaigns by Politecnico di Torino and Geomatics group concern many multi-temporal datasets that have been acquired by different subsequent campaigns in 1997, 1998, 2007, 2012, 2015, by employing various sensors following the evolution of the acquisition techniques offers by geomatics in the archaeological field surveys. In the Sacred Area of the Apollo Sanctuary, two different datasets allow to perform investigation and comparisons before and after archaeological accommodation of the sepulchre of Apollo. A first 3D model has been created from archive images captured by a particular nadir point of view (a man harnessed and suspended from a crane collected photos using a Rollei semi-metric film camera); then an Unmanned Aerial Vehicle (UAV) flight was performed lastly in 2015 by a EBee fix wing drone. On the other hand, in the massive complex of the Bath-Church the deeply damaged eastern wall was kept under observation during years until the securing intervention with a castle of tubes has been achieved: until that moment the pipes structure masks almost completely the wall, even during the last Light Detection and Ranging (LiDAR) survey performed in 2012. The integration with previous images datasets collected before the securing intervention and used to generate a 3D model, want to overcome this limitation in a multi-temporal integration. In such perspective, 3D data derived from digital acquisition and modelling constantly contribute to build a knowledge on the site and help to improve their communication.

2. Multi-temporal archaeological site monitoring

In excavation contexts, for over some ten years, image-based approaches can provide a valuable base for synoptic monitoring of excavation activities and restoration managing in archaeological sites. In the evolution of the metric survey techniques, photogrammetry employed for Heritage documentation, integrated in recent years with TLS, can be practicable both with close-range acquisitions, aerial acquisitions in nadir or oblique camera configuration, and with the close-range quasi-aerial ones, by several devices allowing acquisitions from aerial points of view (poles, balloons, controlled flying kite, etc.). Anyway, multi-sensors, multi-scale and multi-resolution models are complex databases thanks to theirs fitting in the same spatial system designed and measured, in this way they could be designed also as multi-temporal.

Furthermore, likewise the photogrammetry by remote sensing methods with the help of satellite images are quite diffuse in excavation documentation approaches finalized to multi-temporal monitoring aims. Generally, the multi-temporal analysis for observations about the slow evolution of phenomena that characterize the built environment is normally based on satellite imagery and high resolution and / or photographic cartography (orthophotos) with temporal intervals not particularly tight (one year, five years, ten years, twenty years, etc.) (Hadjimitsis *et al.* 2009; Scardozzi 2009; Aicardi *et al.* 2016; Kaimaris *et al.* 2017; Kaimaris, Patias, Georgoula 2017). Anyway, in complex archaeological contexts and in case of high-scale detail needs high-resolution satellite images, due to their scale, their geometric configuration and ultimately their intrinsic features, do not respond comprehensively to the demand of details and information for the scale and complexity of archaeological context in order to clearly identify the excavation progression, in closer temporal windows. In these cases, the opportunity to perform aerial acquisition with UAV systems responds much more to the updating purposes. Here the contribution of 3D metric data provides highly effective results in excavation field, adding to both quickness and sustainability, in term of costs for human involvement and time-consuming operation. In this perspective, 3D data derived from digital acquisition and modelling constantly contribute to build a knowledge on the site: in fact, the combination of digital models and direct observations of the excavations results must operate with the aim of improving the comprehension and preservation of information for the documentation purposes. Furthermore, they help to improve their communication and thus, the enhancement of the dissemination aims. In a simplified framework, we can mention the importance of these following items:

1) Imagery methods collections, based on photogrammetric methods, can now rely on the exploitation of image matching and Structure from Motion (SfM) algorithms, derived from the Computer Vision and can be considered as a quick means for low-cost updating of excavation maps.
2) The planning of topographic measurements and sharing them in time in a single reference system, adding or using many local reference systems related to the first, means allowing to develop multi-sensor projects, and multi-temporal as well.
3) The 3D survey and modelling techniques, as a result, can greatly support many scenarios in the field of archaeological studies and needs. Different models may represent different phases of construction of the complex or the building studied, and through them we can reconstruct the temporal scanning of their transformation in time as well as the assumption of the configuration that it should have had at the time of his life.

3. The documentation project for the archaeological complex of Hierapolis in Phrygia (TR)

The MAIER – Italian Archaeological Mission of Hierapolis operates in the ancient city since long time, up from the 1960s and it is still active. It was directed for first tens of years by Politecnico di Torino, Prof. Verzone and Prof. De Bernardi; then in early 2000s University of Salento with Prof. Francesco D'Andria is at the head of MAIER and this year is moved to Prof. Grazia Semeraro of the same University.

The urban area stretches over a travertine shelf looking onto the broad and fertile valley of the Çürüksu river; the shelf lies between 350 and 425 m asl, rising steadily towards E; on the western side, in contrast, there is a sharp drop towards the plain below. The steep slope is covered with white calcareous formations, produced by the springs whose waters emerge from the central area of the city as a result of the earthquakes of the medieval period. Indeed, the history of the city, founded in the 3rd century BC, has been characterized by destructive seismic events, which have also marked the main phases of its urban development (D'Andria 2003). The ancient monumental buildings interested by the next Geomatics tests (Fig. 1) with different sensors (Tab. 1) are largely affected by natural disasters and site characterization and transformations occurred to the entire city.

	1997	2002	2007	2012	2015
Campaign A – Apollo Sanctuary		*photo by crane*			*UAV*
Ancient Bath – Church	*photo by balloon*		*C-R photogr.*	*LiDAR*	*UAV*

Tab. 1 – The synoptic selection of multi-temporal datasets during archaeological survey campaigns by MAIER.

Fig. 1 – a-b) Hierapolis Atlas (D'Andria, Scardozzi, Spanò 2008), map n°13 and n°35, zoomed excerpt on Bath-Church complex and eastern wall (sx) and Apollo Sanctuary and its Building A (dx); c-d) An image of the Bath-Church acquired by balloon (sx) and an image of Apollo Sanctuary (dx) from: https://www.hierapolis.unisalento.it/.

3.1 *The ancient Bath-Church*

The Roman outer bath complex is placed outside to the N of the main city and certainly was one of the centres of urban enlargement in the Antonine Age (Fig. 1, a-c), along with the giant North Agora and the North Theatre. The walls of the Roman bath are entirely built by large squared travertine blocks, basically placed without mortar in order to make up a dry-stone wall, with only sporadic and very thin plaster joints; the wall covering is completely lost. The complex is particularly in danger due to several seismic events over the past centuries. The devastating earthquake of the second half of the 4th century AD surely damaged many portion of the northern district of the city (Verzone

1954; D'Andria 2015). During the last two decades, such imposing building have been object of the applying of several metric survey techniques and some structural consolidation interventions (D'Andria, Caggia, Ismaelli 2012; Mighetto, Galvagno 2012). The documentation was converged to investigate the architectural composition of the building, the analysis of the functional stratified transformation and, at last, the deep geometrical description of the serious alteration of walls and vaults and their widespread risky instabilities.

3.1.1 Documentation campaign of the eastern wall in the ancient Bath-Church

During the 1997 Archaeological Mission, a curbed balloon equipped with a film camera was employed for a comprehensive documentation of most part of excavation sites in the archaeological park by Cesare Cassanelli from the research group of Scuola Normale Superiore di Pisa. The result is a complete photographic archive of the *de facto* state of the ancient city in 1997 but not designed to metric documentation purposes. The attempt that has been carried out here is to extract a 3D model with the digitalization of the dataset related to the Bath-Church (Fig. 1, c). The photonegative film of a commercial film camera 24×36 mm has been digitalized with Canon scanner in 1,200 dpi. The image quality and resolution were not planned for photogrammetric reconstruction with a suitable camera and this caused, together with the image focusing not always properly obtained, the failure of the densification algorithm, despite the external orientation of cameras has been quite successful (Fig. 2, a-b) and the estimation of camera positions was computed. The roughness of the calculated surfaces is a key effect of grainy and blurry images used as baseline data.

In 2007, another phase of documentation was carried out with a complete close-range acquisition and processing of the external front of the eastern wall of ancient *calidarium*. The digital camera Panasonic Lumix captured 9 images of the sloping wall, with sensor size 7.2 mm×5.3 mm, 35 mm focal and 2,560×1,920 pixel images dimension (Fig. 2, b). A 3D model was then calculated (Tab. 2).

The problem of the high scale documentation of the whole Bath-Church structure appeared towards in the external side of the eastern wall, focus of

	2007
Campaign	9
Shooting distance	18 m
GSD	6.4 mm/px
Tie points	2,200
Dense Cloud	6,634,000
Mesh triangles	1,303,000

Tab. 2 – Parameters and results of alignment/densification process from 2007 Campaign.

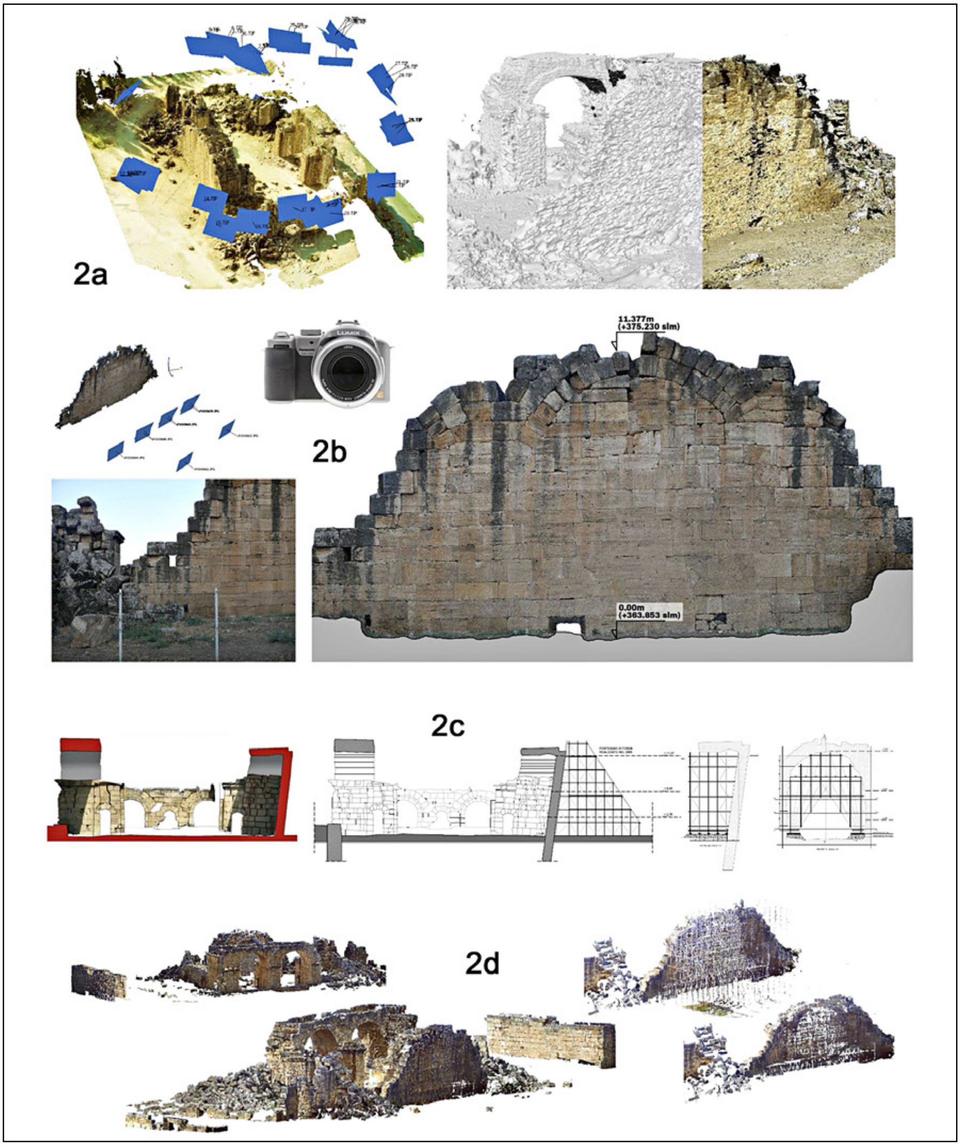

Fig. 2 – The 3D model generated with 1996 images: a) (sx) Estimated position of the camera equipping the curbed balloon and (dx) 3D mesh and dense cloud from unsuccessful densification process; b) Terrestrial acquisition on eastern wall of Bath-Church in 2007 campaign with digital camera Panasonic Lumix DMC-FZ50 (sx) and orthoimage of the wall from close-range acquisition (dx); c) The pipes structure project in 2012 for support of internal and external front of the eastern wall (Mighetto, Galvagno 2012); d) LiDAR data in 2012, with and without the pipes structure: it supports the masonry wall displacement but it causes occlusion in wall documentation too (Invernizzi, Spanò, Alfieri 2014).

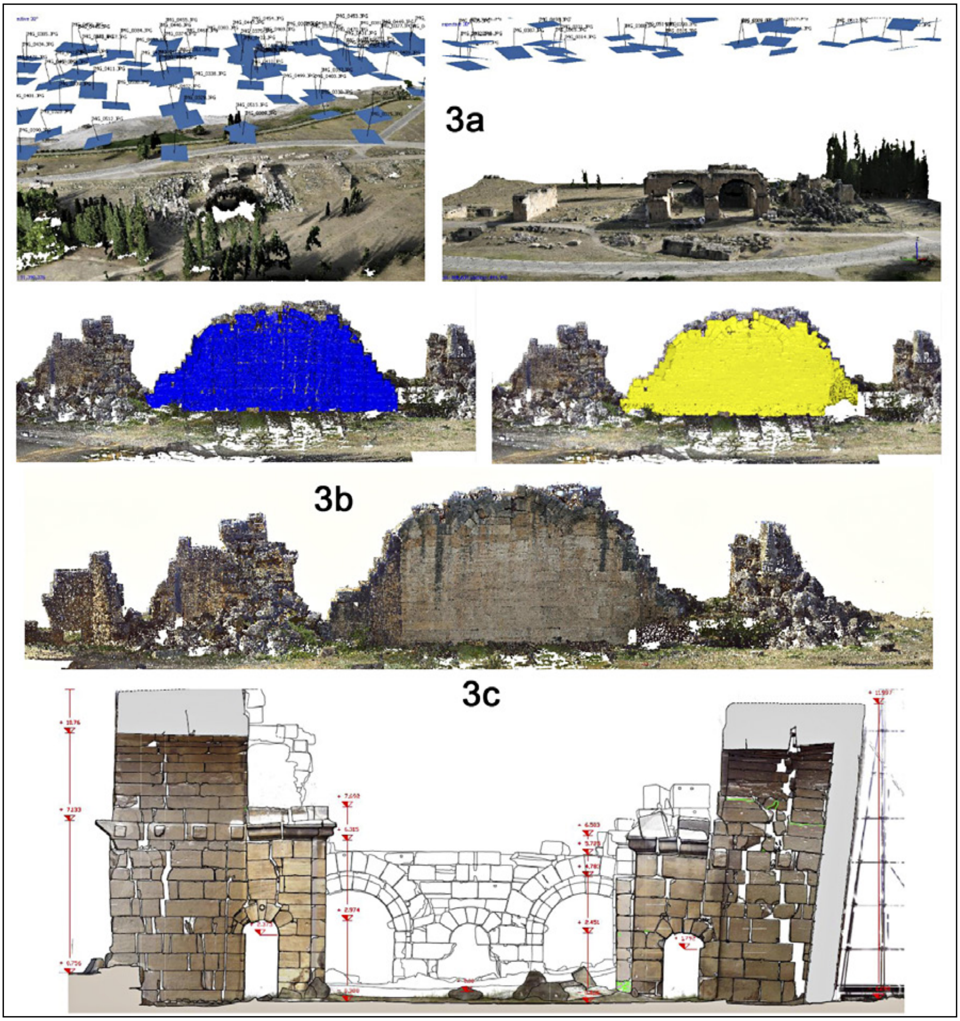

Fig. 3 – a) 3D model from aerial photogrammetry in 2015 by Ebee flight: data is lacking in the area of the wall; b) LiDAR data with highlighted in blue the part concerning to the wall (sx) and in yellow (dx) the photogrammetric contribution of 2007 acquisition superimposed on the LiDAR data, in the central image beneath the data integration; c) Transversal section across the eastern wall.

the security intervention with the introduction of metal structures (Mighetto, Galvagno 2012) (Fig. 2, d). From that moment and during all the subsequent survey campaigns the wall was sheltered by a dense coverage of pipes: in 2012, the documentation project carried out by Politecnico LiDAR through was affected by these elements.

The documentation aims performed by laser scanning technique were: the deepen geometrical description of the serious alteration of walls and vaults and their widespread risky instabilities; the 3D model describing the peculiarities of each travertine block, such as the roughness, the breakings and the micro-breakings; the geometry of almost each masonry block, explicitly accounted and converted to be used as the input in order to assess the present condition and properly formulate hypotheses for the necessary interventions by Finite Element Modelling (FEM) and Analysis (FEA) for the structural assessment (Inverniz-zi, Spanò, Alfieri 2014). The model of the whole Bath-Church complex has been derived from 43 scans positions: 22 from ground level, along the outer limit of the building; 16 from ground level, inside the *calidarium*; no. 5 from the top of some still standing or collapsed walls, in order to obtain an almost complete scan covering (Fig. 2, d). The scans elaboration, cloud optimization and meshing operations were a very time-consuming and significant phase of processing. Moreover, the eastern wall was covered by pipes thick structure.

In 2015, the Geomatics group of Politecnico di Torino performed an integrated project of documentation via terrestrial LiDAR and aerial photogrammetry by fix wing Ebee drone (see in detail next paragraph 3.2.1). A block of images was captured by UAV system at 150 m height but the 3D model derived did not respond to the level of detail specifically on the focus on the eastern wall (Fig. 3, a). Besides, photogrammetric resulting products such as orthophotos and the Digital Surface Model (DSM) cannot be compared to the extreme detailed models offered by terrestrial laser survey or close-range photogrammetry dated back in 2007 before the pipes structure occlusion, particularly regarding the vertical portions of the wall, which are not achieved in the most effective manner by projecting rays.

Thus, in those points where metal pipes structure occluded the scans visibility, the final winning approach was to integrate (Fig. 3, b) in a multi-sensor 3D model the high detailed geometrical documentation by LiDAR scans with the help of the 3D data from close-range photogrammetry in very-high scale. It is possible to see in Tab. 3 how the 3D metric data are comparable and then can be integrated to complete the metric documentation (Fig. 3, c).

	2007	2012
Campaign Point Cloud	6,514,041	6,995,339

Tab. 3 – Point cloud comparison between the two sensors that can be integrated.

3.2 *The sacred area of the Apollo Sanctuary*

The sanctuary (Fig. 1, b-d) built in the central area of the city is dedicated to Apollo, whose oracular cult is documented by inscriptions discovered during the excavations. The sacred area, changed to a monumental layout in Augustean Age, but just in use in Hellenistic period, is organised upon three terraces sloping toward W, near a huge fault from which concentrations of carbon dioxide pour out. After the excavations in the 1960s, which had led to the identification of the so-called "Building A", interpreted as temple, the resumption of research in 2001 has enabled the identification of two other buildings ("B" and "C") and clarify many aspects related to sacred practices (Semeraro 2012, 2016) (Fig. 4, a).

3.2.1 Documentation campaigns on Building A

In year 2002, during the archaeological mission another photogrammetric approach was tested in order to acquire a sort of aerial view for a high-scale detail documentation on the Apollo Sanctuary, Building A. A man harnessed and equipped with a semi-metric camera was suspended from a carrier crane with a mean height from ground of 10 m (Fig. 4, b). The sensor was a Rolleiflex SLX 6006 semi-metric film camera with 60×60 mm images. According to the acquisition condition the recovery area on ground of the photogram would have been approximately 15 m. A set of ground points was measured both in natural points and with the help of b/w markers for orientation and georeferencing process. The data calibration of the Rollei camera for internal orientation are:

F=40 mm
F_{calib}*=40.870 mm*
PPS (Principal point of symmetry): X=0.040; Y=0.280
Radial distortion: $-0.130<d_r<+0.075$

The complex acquisition conditions and the non-constant control of shutter location in stereoscopic position in relation to the object, with a non-uniform overlapping, led to a lack of external orientation in the photogrammetric images block at that time.

Instead, nowadays the improved software for digital photogrammetry based on image-matching algorithms from computer vision Structure from Motion (SfM), allow the automatic orientation phase of image blocks with the extraction of several Tie points for the reconstruction of the estimated cameras position. In this sense, the diffusion of the new digital tools could led to a unique opportunity, that is the exploitation and valorisation of archival records. The 12 images in the photonegative film have been developed in slides, that have been digitized with Canon scanner in 1200 dpi. Each image 60×60 mm has: resolution of 2,835×2,835 px; pixel size = 0.0212×0.0212 mm (21.2×21.2 µm).

Then with the use of a commercial photogrammetric software, the well know Photoscan Pro by Agisoft (http://www.agisoft.com/; accessed: 31/03/2017), the camera calibration was estimated by the software algorithms and the images were oriented in order to produce the 3D model, of the area

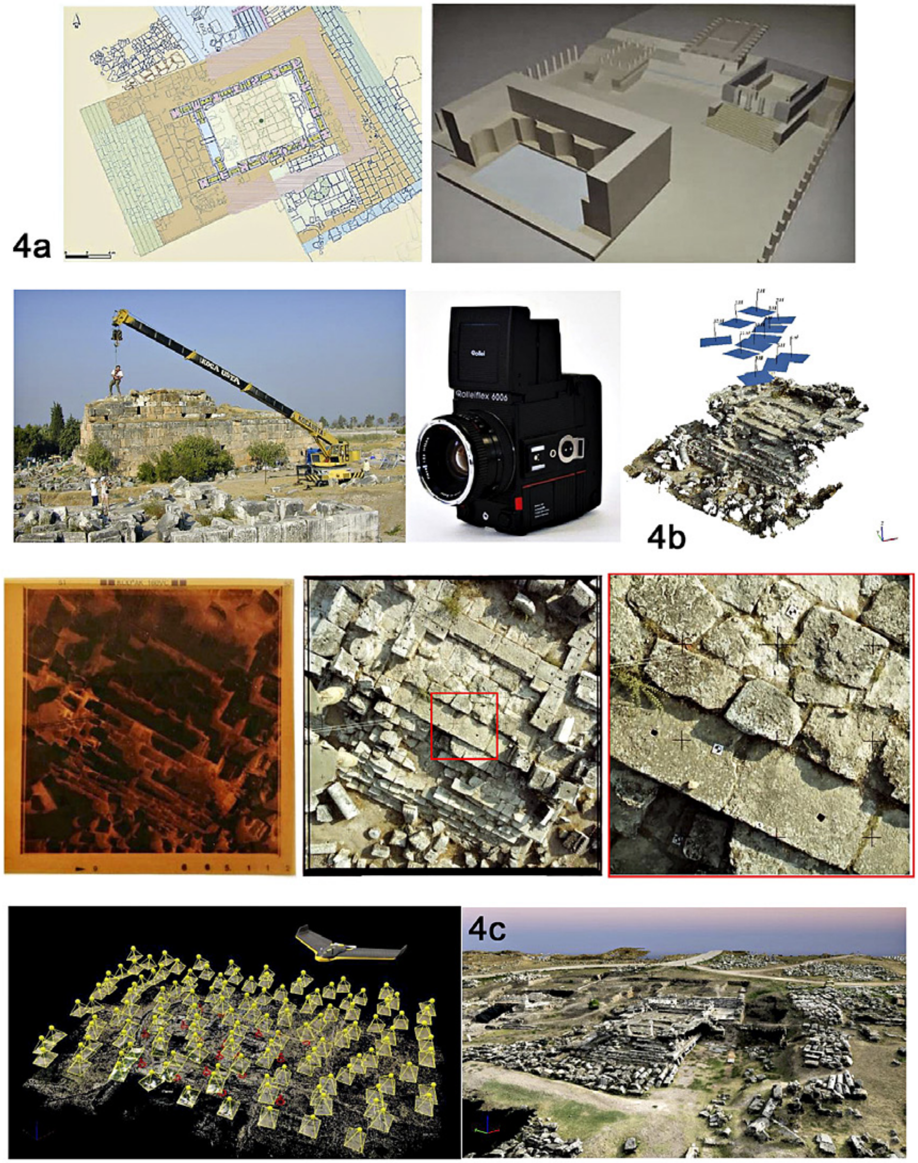

Fig. 4 – a) The Apollo Sanctuary in (sx) reconstruction of 1st century AD (Giulio-Claudia Age, phase II) and (dx) 3rd century AD (Severian Age, phase III); b) The temple in the 2002 acquisition campaign: (up) the photos collection using a Rolleiflex camera by a man harnessed and suspended from a crane (down), the photonegative film and the photogram, with a zoom excerpt; c) The sacred area in 2015: the aerial photogrammetric acquisition by fix wing drone, after the archaeological accommodation of the Apollo sepulchre; camera position and orientation (sx), and dense cloud (dx).

with the dense point cloud and the 3D triangulated mesh. For data processing a performing workstation was used: CPU Intel(R) Core i7-6800k, 3.4 GHz, RAM 128 GB, NVIDIA quadro M²000.

The calibration data estimated by the software algorithms during orientation process are:

F_{estim}= 1951.6px (41.374 mm)
PPS (Principal point of symmetry): X= 0.0132; Y= 0.0043

The 3D model can be georeferenced in the WGS84 Reference System with a set of topographic GCP measured in 2002 on the ground (natural and markers points) in the global reference system. As an alternative, the challenge will be the georeferencing and Bundle Block Adjustment related to a set on archival images with natural points from a subsequent model calculated with a set of images acquired by drone in 2015 campaign. As it is described below, points are identified and extracted in some areas not involved in blocks accommodation for Building A.

In the 2015 Mission, the Geomatics group from Politecnico di Torino operates in the excavation area with a project of integrated aerial and terrestrial documentation in some monumental zones of the ancient city. Here we present the photogrammetric flight performed on the Sacred Area of Apollo Sanctuary with a fix wing platform (Fig. 4, c). The eBee™ autonomous flying drone is one of the lately updated and cost-effective platform, a consumer product by SensFly Company (https://www.sensefly.com/drones/eBee.html, distributed in Italy by MENCI: http://www.menci.com; accessed: 31/03/2017). It is a fully automatic UAV with a central body, where all the electronics and main communication hardware are included. According to the SenseFly specification, the platform height with the camera is about 0.70 kg with a wingspan of 96 cm. The system is connected to a Ground Control Station (GCS) able to define all the characteristics of the flight and supervising in real time the platform during the flights. The UAV eBee was equipped with the Power shot Canon S110 RGB sensors tailored to the system. The S110 RGB is a 12 MP COTS (Commercial Off-the-Shelf) camera able to acquire regular image data in the visible spectrum (CCD size 7.44×5.58 mm, pixel pitch 1.86 µm, focal length 5.20 mm) (Chiabrando *et al*. 2016).

A set of 16 natural points were detected on the aerial model (Fig. 5, a), and they can be easily marked on the images acquired in 2002, in those parts of the building in which the archaeological accommodation did not occurred. With the help of these points the images block regarding the older acquisition can be calculated (Fig. 5, b-c), adjusted, georeferenced, evaluated in its accuracy (Tab. 4).

It is now possible also to compare the model (A-2002) with the photogrammetric one by drone (B-2002) (Tab. 5).

	Error on 11 GCPs (mm)				Error on 5 CPs (mm)			
	X	Y	Z	error	X	Y	Z	error
RMSE	7.918	2.703	4.698	5.106	9.254	13.819	7.292	10.121
Mean	6.874	2.181	3.372	4.142	5.533	11.863	5.871	7.756

Tab. 4 – Results on GCPs and CPs for Bundle Block Adjustment.

	2002 (A)	2015 (B)
Images	12	127
Altitude	10 m	100 m
GSD	5.08 mm/px	21 mm/px
Area	330 m^2	110,400 m^2
Tie points	165,355	937,990
Dense Cloud	13,438,442	223,708,806
DSM res	4,8 mm/px	21 mm/px
Mesh triangles	2,600,000	10,000,000

Tab. 5 – Parameters and results of alignment/densification process from 2002 and 2015 datasets.

Interesting data are emerging firstly about the quality of accuracy checked on the model (A), and then about comparison of dense clouds in the same area (Fig. 5, d). Under the comparison between them it is possible to demonstrate that, unless parts of minor differences, the whole area has relative discrepancy of ±0.06 cm mean value. The exceptions are the parts in red colour with differences >10 cm, supposed belonging to the modifications of archaeological accommodation. The mapping representation expresses the visualization for the chance detection between 2002 and 2015, through a point clouds filtering according to the comparison between clouds.

4. Conclusion and future perspectives

In the two cases presented there is an attempt to follow the evolution of Geomatics techniques applied to archaeology in an exceptional site that is the stratified and for a long time studied city of Hierapolis in Phrygia. One of the main goals of this experience, in the framework of improving the enhancement of the dissemination aims for cultural heritage, is the documentation by modelling archaeological sites during times and using diachronic data. The possibility of actualizing and managing in a 3D space also the old archival data is an interesting approach and a promising solution for ongoing investigations. To provide a simplified and schematic framework of opportunities we can mention the following items that deserve attention in future research:

– The range-based methods based on LiDAR scans are an increasingly used solution, but considering the time needed for recording, registering, filtering

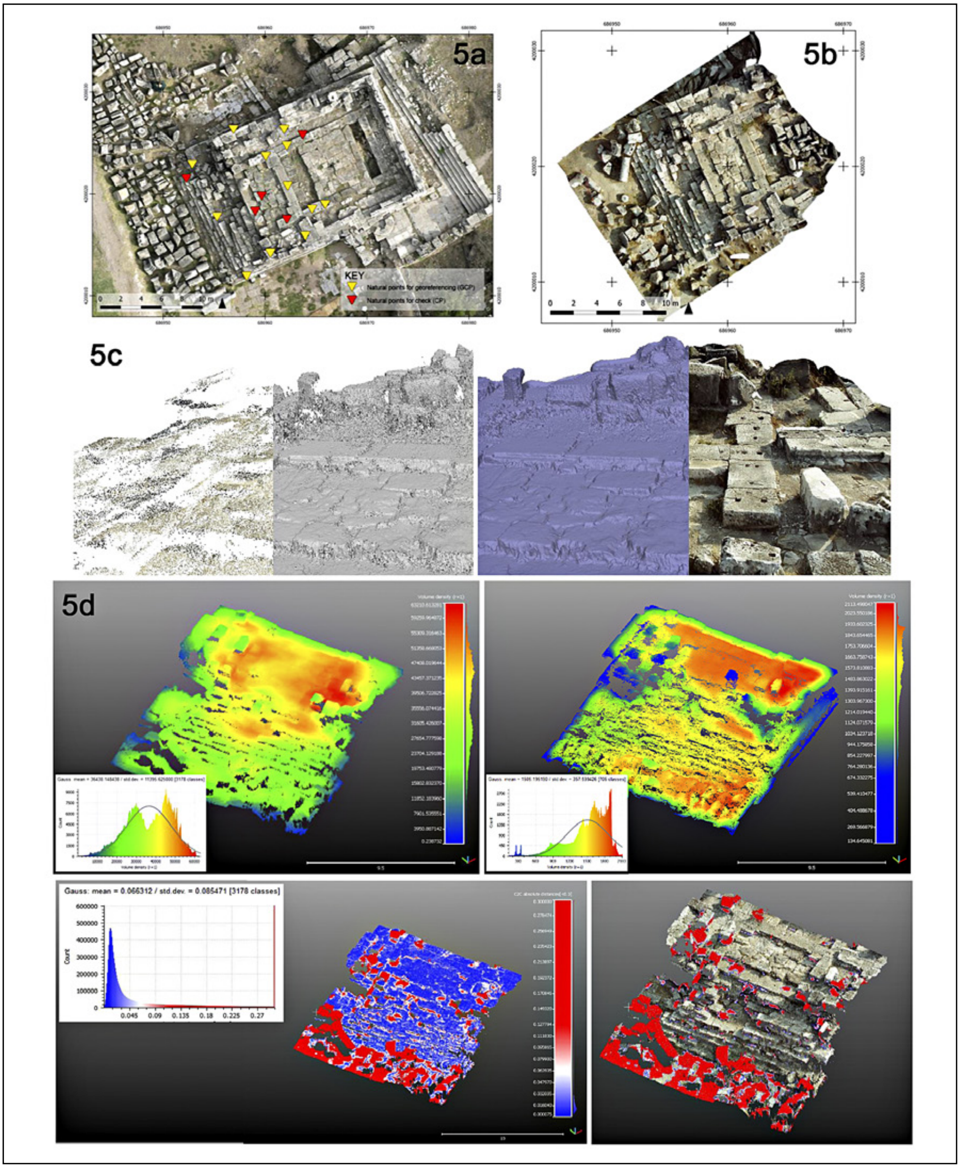

Fig. 5 – a) The Building A from 2015 acquisition by drone: orthoimage and extracted natural GCPs; b) The Building A from 2002 Rolleiflex acquisition: orthoimage; c) Views of point cloud densification (sx) and triangulated mesh (dx) with and without radiometric information, regarding the 3D model dated 2002 with Rolleiflex film camera acquisition; d) Investigation on density distribution of points clouds for (A-2002), mean density 36,400 pt/m³ (st.dev 11395), for (B-2015), mean density 1,500 pt/m³ (st.dev 358), and comparison between points clouds spatial geometry (mean discrepancy 0.06 m) and the mapping of changing areas.

and decimation of points clouds, as well as the construction of the 3D mesh, the LiDAR technique, which has established itself as it provides extremely detailed and accurate outputs, is definitely heavy and less sustainable in relation to photogrammetry; in fact it is used when strictly necessary.

– Imagery methods, that means the usage of images collections followed by photogrammetric methods, which can now rely on the exploitation of image matching and SfM algorithms derived from the Computer Vision field, can be considered nowadays as a quick means for a low-cost updating of the excavation maps. So, overlapping images collected both in older campaign (from the ground, from poles, from curbed balloons, by a man harnessed and suspended from a crane) and nowadays thanks to close-range or modern UAV techniques, we are able to provide suitable products, such as orthophotos, DSM, or enriched meshed 3D models, on which it is possible to collect other reading data from activities such the ones derived from excavation.

– The planning of a coherent and articulated topographic project allows georeferencing and sharing in time the models: multi-sensor (that is, range-based, LiDAR, or image-based photogrammetry), multi-scale, and multi-temporal as well.

– On the side of the results exploitation, the indicated 3D models techniques, on which products are based, can facilitate the study of excavation data, with the benefit of 3D graphic configurations to represent different phases of construction of the complex or the building studied. So, through different models it may be possible to reconstruct the temporal scanning of their transformation in time as well as the assumption of the configuration that must be taken at the time of his life. This will certainly lead to formulate the virtual reconstruction hypothesis of the ancient structures no longer readable.

– These scenarios can be effectively reported using models to scholars involved in research and to the wider audience of non-experts for educational divulgative ambitions.

Acknowledgements

The authors would like to thank especially the MAIER in the person of Prof. Francesco D'Andria for the experience of fieldwork in Hierapolis 2015 Mission at Pamukkale (TR). Thanks also to Arch. Giacomo Patrucco for his help in data processing.

Filiberto Chiabrando, Giulia Sammartano, Antonia Spanò
Politecnico di Torino
Dipartimento di Architettura e Design
filiberto.chiabrando@polito.it; giulia.sammartano@polito.it; antonia.spano@polito.it

Grazia Semeraro
Università del Salento
Dipartimento di Beni Culturali
grazia.semeraro@unile.it

REFERENCES

Aicardi I., Nex F., Gerke M., Lingua A.M. 2016, *An image-based approach for the co-registration of multi-temporal UAV image datasets*, «Remote Sensing», 8, 9, 779.

Campana S. 2017, *Drones in archaeology. State-of-the-art and future perspectives*, «Archaeological Prospection», February 2017 (http://www.scilit.net/article/10.1002/arp.1569; accessed: 31/03/2017).

Chiabrando F., D'Andria F., Sammartano G., Spanò A. 2016, *3D modelling from UAV data in Hierapolis of Phrigia (TK)*, in J.L. Lerma, M. Cabrelles (eds.), *ARQUEOLÓGICA 2.0. 8th International Congress on Archaeology, Computer Graphics, Cultural Heritage and Innovation (Valencia 2016)*, IEEE, 347-349.

D'Andria F. 2003, *Hierapolis of Phrygia (Pamukkale): An Archaeological Guide*, Ege Yayınları, Istanbul.

D'Andria F. 2015, *Terme Chiesa*, in G. Scardozzi (ed.), *Hierapolis di Frigia VII. Nuovo atlante di Hierapolis di Frigia*, Istanbul, Ege Yayınları.

D'Andria F., Caggia P., Ismaelli T. (eds.) 2012, *Hierapolis di Frigia V. Le attività delle campagne di scavo e restauro 2004-2006*, Istanbul, Ege Yayınları.

D'Andria F., Scardozzi G., Spanò A. (eds.) 2008, *Atlante di Hierapolis di Frigia*, Ege Yayınları, Istanbul.

Farella E., Menna F., Nocerino E., Morabito D., Remondino F., Campi M. 2016, *Knowledge and valorisation of historical sites through 3D documentation and modelling*, «The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences», 41-B5, 255-262.

Hadjimitsis D.G., Themistocleous K., Agapiou A., Clayton C.R.I. 2009, *Monitoring archaeological site landscapes in Cyprus using multi-temporal atmospheric corrected image data*, «International Journal of Architectural Computing», 7, 1, 121-138.

Invernizzi S., Spanò A., Alfieri C. 2014, *Combined laser surveying and finite element modeling for the structural assessment of masonry structures at the Hierapolis outer bath complex*, in F. Peña, M. Chávez (eds.), *9th International Conference on Structural Analysis of Historical Construction SAHC 2014 (Mexico City 2014)*, 1-12 (http://www.hms.civil.uminho.pt/sahc/2014/topic04-fullpaper011.pdf; accessed: 31/03/2017).

Kaimaris D., Georgiadis C., Patias P., Tsioukas V. 2017, *Aerial and remote sensing archaeology*, «International Journal of Computational Methods in Heritage Science», 1, 1, 58-76.

Kaimaris D., Patias P., Georgoula O. 2017, *Google Earth revisited: Case studies at the plain of Larissa (Thessaly, Greece)*, «International Journal of Computational Methods in Heritage Science», 1, 1, 77-88.

Kersten T.P., Lindstaedt M. 2012, *Potential of automatic 3D object reconstruction from multiple images for applications in Architecture*, «International Journal of Heritage in the Digital Era», 1, 3, 399-420.

Mighetto P., Galvagno F. 2012, *Le Terme-Chiesa e la sfida della conservazione dei segni dell'attività sismica*, in D'Andria, Caggia, Ismaelli 2012, 469-482.

Moussa W., Abdel-Wahab M., Fritsch D. 2012, *An automatic procedure for combining digital images and laser scanner data*, «The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences», 39-B5, 229-234.

Remondino F., Rizzi A. 2010, *Reality-based 3D documentation of natural and cultural heritage sites-techniques, problems, and examples*, «Applied Geomatics», 2, 3, 85-100.

Scardozzi G. 2009, *Multitemporal satellite high resolution images for the knowledge and the monitoring of the Iraqi archaeological sites: The case of Seleucia on the Tigris*, «Photo interpretation European Journal of Applied Remote Sensing», 4, 143-160.

Semeraro G. 2012, *Ricerche nel santuario di Apollo*, in D'Andria, Caggia, Ismaelli 2012, 293-324.

Semeraro G. 2016, *Ricerche nel Santuario di Apollo (2007-2011)*, in F. D'Andria, P. Caggia, T. Ismaelli (eds.), *Hierapolis di Frigia VIII*, 1-2. *Le Attività delle Campagne di Scavo Restauro 2007-2011*, Istanbul, Ege Yayınları.

Verzone P. 1954, *Le chiese di Hierapolis*, «Cahiers Archéologiques», 7, 37-61.

ABSTRACT

Archaeological site monitoring and updating can nowadays benefit from the contribution of geomatic techniques. In recent times, image-based and range-based measurement systems have become increasingly interesting in excavation processes for monitoring purposes and large scale mapping, both from a terrestrial and aerial point of view. The paper will focus on the great challenge of monitoring sites over time, integrating and conforming multiple data coming from previous metric survey projects and image data collected in the past for different purposes. The test-site was the complex archaeological landscape of the ancient city of Hierapolis in Phrygia on which the MAIER – Italian Archaeological Mission of Hierapolis has operated since the 1960s and where the Politecnico di Torino conducted several survey campaigns. A set of multi-temporal datasets acquired in a series of campaigns in 1997, 2002, 2007, 2012, 2015 are presented, as well as their 3D multi-sensor models; the older dense models generated with archival images are intended to be compared and integrated with newer models generated by the LiDAR scans in 2012 and the UAV systems employed in the last mission in 2015. In particular, the case study was the massive complex of the ancient Bath-Church in the norther part of the city below the Northern Necropolis, and Building A of the Apollo Sanctuary, in the central Sacred Area near the Ancient Theatre. In these sites, many different sensors have been experimented with over the years and preliminary multi-temporal data integration has been tested in order to up-date and improve older archival records based on collected images and related to newer and updated documentation projects.

28.2

2017

ARCHEOLOGIA
E CALCOLATORI

Knowledge, Analysis and Innovative Methods
for the Study and the Dissemination of Ancient Urban Areas
Proceedings of the KAINUA 2017 International Conference

€ 72,00

ISSN 1120-6861
e-ISSN 2385-1953
ISBN 978-88-7814-785-0
e-ISBN 978-88-7814-786-7