Sandro Parrinello
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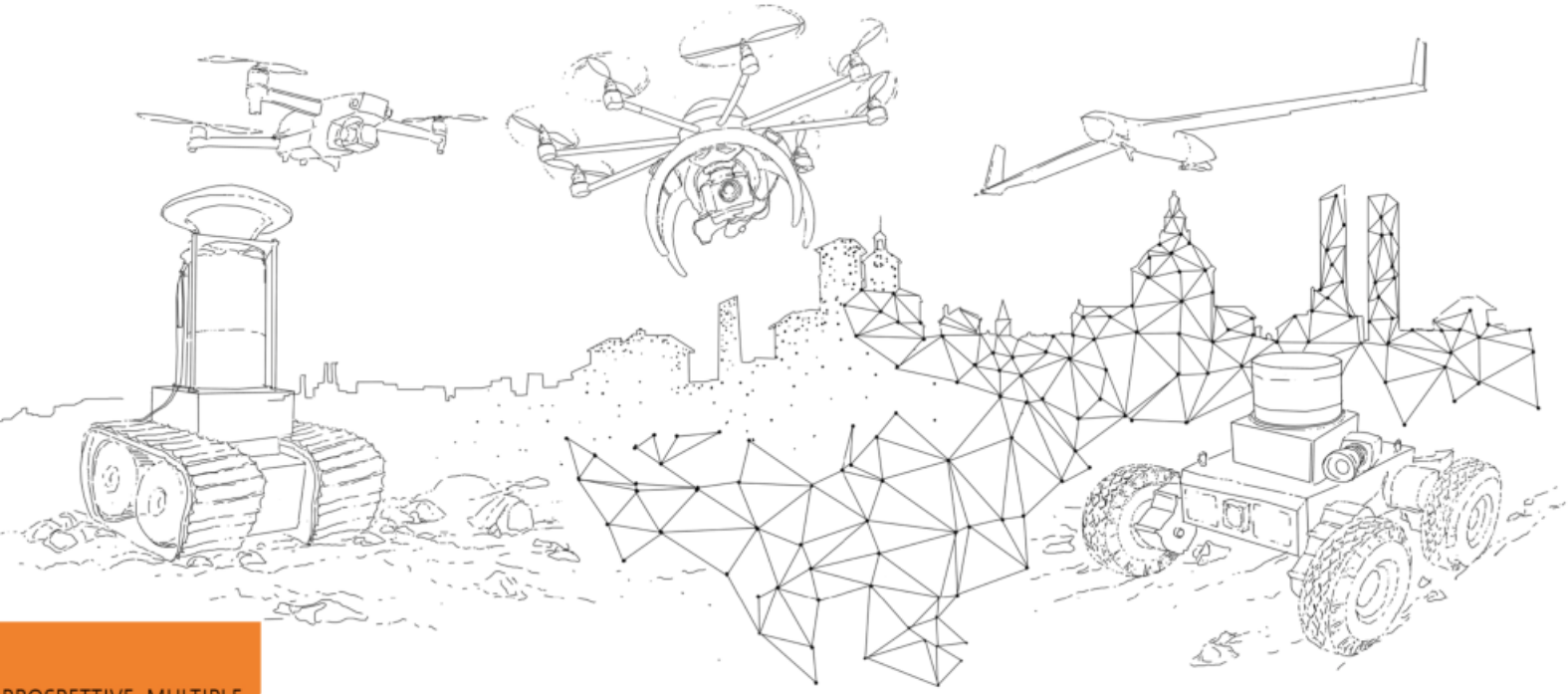
D-SITE

Drones - Systems of Information on culTural hEritage for a spatial and social investigation

Volume 2



PROSPETTIVE MULTIPLE
STUDI DI INGEGNERIA
ARCHITETTURA E ARTE

PaviaUniversityPress

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D-SITE, Drones - Systems of Information on Cultural Heritage for a spatial and social investigation / Sandro Parrinello, Salvatore Barba, Anna Dell'Amico, Andrea di Filippo (edited by) - Pavia: Pavia University Press, 2022. - 684 p.: ill.; 21 cm.

(Prospettive multiple: studi di ingegneria, architettura e arte)

ISBN 978-88-6952-159-1
ebook 978-88-6952-160-7

The present publication is part of the series "Prospettive multiple: studi di ingegneria, architettura e arte", which has an international referee panel. "D-SITE, Drones - Systems of Information on Cultural Heritage for a spatial and social investigation" is a scientific text evaluated and approved by double blind peer review by the Scientific Editorial Board.

Translation of chapters and treatment of citations and bibliography are due to the respective authors.

Pavia University Press
Edizioni dell'Università degli Studi di Pavia
info@paviauniversitypress.it
www.paviauniversitypress.it

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Graphic project
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On cover: Drawing by Francesca Picchio and Sandro Parrinello
First edition: june 2022.

Stampa: Logo S.r.l. – Borgoricco (PD)

The volume consists of a collection of contributions from the conference "D-SITE, Drones - Systems of Information on Cultural Heritage for a spatial and social investigation". The event, is organized by the experimental laboratory of research and didactics DAda-LAB of DICAr - Department of Civil Engineering and Architecture of University of Pavia, and MODLab of DICIV - Department of Civil Engeenering of University of Salerno. The publication co-funded by the the University of Pavia, the University of Salerno, and the Italian Ministry of Foreign Affairs and International Cooperation.

D-SITE Conference is organized by:

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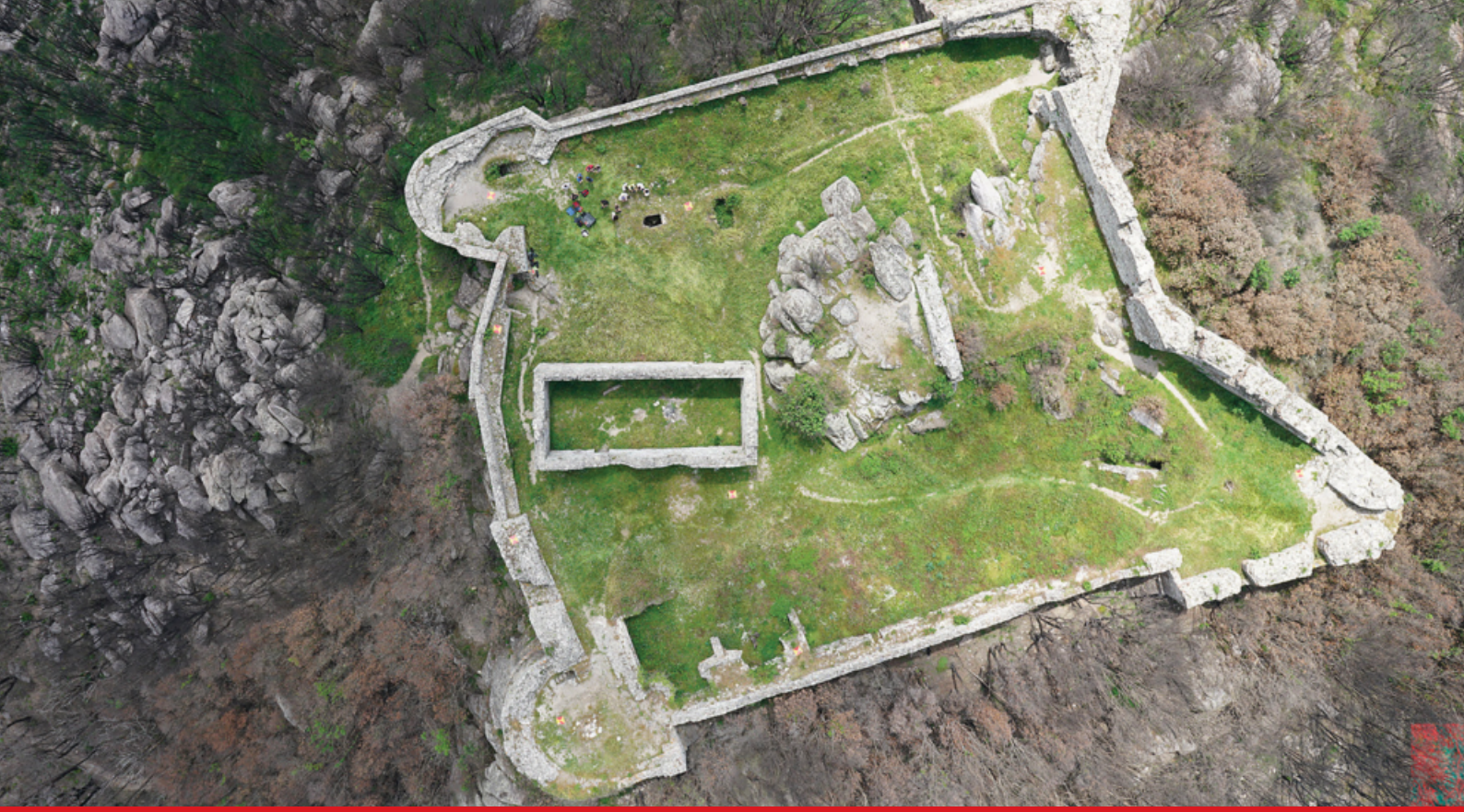

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Keywords:
UAV, photogrammetry, data reliability, point cloud, Verruca fortress.

ABSTRACT

The paper describes the digital survey project of the Verruca fortress, which is located on the summit of Monte Serra, in the Pisan mountains. Today the fortress is in a state of ruin, and recently a summer fire caused the loss of the vegetation that had massified around the building, thus allowing to program the analysis of the walls of the fortress to deepen its construction history and state of material and structural conservation.

the fortress survey project integrates range based, image based and UAV technologies, focusing attention on the methodologies used to ensure the high morphological reliability of the data obtained from the survey, in a very complex area to reach.

The results of the survey made it possible to reconstruct a whole series of graphical drawings that made it possible to deepen the architectural and historical analyzes on the fortress.

The aerial photogrammetric survey for the documentation of the Cultural Heritage: the Verruca fortress on the Pisan Mountains

1. Introduction

The paper describes the digital survey project of the Verruca fortress, which integrates range-based, image-based and UAV technologies, focusing attention on the methodologies used to ensure the high morphological reliability of the data obtained from the survey in an area that is very difficult to reach. (Figure 0)

The fortress is located on the summit of Mount Serra, in the Pisan mountains with the aim of controlling the valley of the Arno river, near its outlet to the sea. It was built by the Pisans in the 10th century and has always been considered of great strategic importance for the maintenance of power (Francovich, Gelichi 2003). Florence and Pisa in the 15th century fought over the possessions and strategic points on the Pisan mountains for a long time until the fortress was definitively taken in 1503, the year in which it was visited by the great Florentine military architects, Sangallo and Leonardo, at the behest of Machiavelli (Pedretti 1972); immediately afterwards the defenses are modernized, in such a way as to be able to defend itself from the shooting of firearms. A few years, due to the loss of strategic importance of these lookout points, the fortress was slowly abandoned. Today it is in a state of ruin, and recently a summer fire caused the loss of the vegetation that had massified around the building, thus allowing to program the analysis of the walls of the fortress to deepen its construction history and state of material and structural conservation. (Figure 1)

In May 2019, a collaboration began between the municipality of Vicopisano, on which part of the fortress property stands, and the Department of Architecture of the University of Florence to carry out the architectural surveys of the fortification; the fortress survey project involved the experimental use of the most up-to-date laser scanner, drone and GPS digital survey tools, to create a highly reliable digital model; the fortress had already been partially surveyed in the past finding great difficulties in measuring the external parts, along the steep slopes, where it is possible to see how the building rests directly on the rocks that characterize the Serra mountain and make it derive its name. The 3d models deriving from laser scanner survey and drone photogrammetry have been joined together in a single highly reliable textured model. To ensure the reliability of the digital models reconstructed with the different acquisition techniques, particular attention was paid to the comparison between the morphologies of the point clouds obtained and to the simultaneous verification

Figure 1. View of the mountain top from the remains of the nearby convent of San Michele alla Verruca.

of significant points measured both in local and geo-referenced coordinates; to ensure the reliability of the individual models, it was also necessary to pay attention to the data registration phase.
The results of the survey made it possible to reconstruct two-dimensional and three-dimensional graphs that allowed to deepen the architectural and historical analyzes of the fortress; it raises a lot of interest in the study of the evolution of fortresses at the end of the 15th century and in the activity as a military architect both by Sangallo and by Leonardo da Vinci.

2. Architectural survey

The position of the Verruca fortress does not present optimal conditions to be able to plan the measurement operations: the survey of the areas inside the walls is not so complex, as the outside, which is arranged on a steep slope with thick vegetation that does not facilitate the passage of operators, instruments and measurements. Despite this, some instrumental surveys have been carried out in recent decades, which did not however allow the detailed description of the walls, and presented some approximations as regards the morphologically more complex parts of the structures: the need for a detailed survey to interpret, following a scientific method, the state of conservation and the evolution of the building led to the design of a more modern and accurate survey campaign.
The recent arson attacks, which hit the top of Mount Verruca, have at the same time partly favored the design and implementation of new measurement campaigns, adopting in this case digital data acquisition systems. In particular, three different acquisition campaigns were carried out:

- laser scanner equipment to create a model that describes the morphology of the building in detail;
- SfM photographic acquisitions from the ground to create three-dimensional models that describe the materiality of the walls;
- aerial photogrammetry with the use of drones, to create a mapped model of the whole complex.

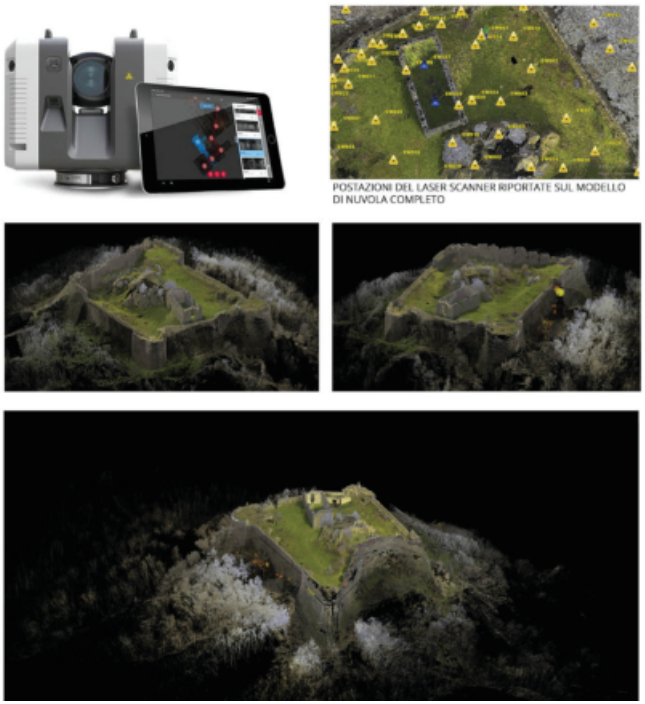

Figure 2. Range-based survey methodologies, used for the reconstruction of the fortress.

In this article we will not go into the acquisition methodology used for each acquisition campaign, which will be further explored elsewhere, but in particular we will deal with the photogrammetric survey from drone and the integration with the other acquisition systems.

3. Methodologies

The laser scanner survey of the Verruca fortress was designed to describe all the surfaces of the architecture with a definition that would allow the graphic rendering of the drawings necessary for the preparation of the diagnostic investigations (Bigongiari, Pancani 2020).
The scans were carried out with the Leica RTC360 instrument, whose characteristics allowed the rapid completion of highly reliable measurements: the scanner

Figure 3. Image based and UAV survey methodologies, used for the reconstruction of the fortress.

in fact is able to measure over two million points per second, creating hd panoramic photographs; the 5 cameras positioned on the edges of the instrument also allow the recognition of the scene in which the scanner is located and its movements, allowing the alignment of the scans directly on the field. The result of the acquisitions produced a point-cloud in local coordinates resulting from the alignment of 145 scans. (Figure 2)
The 3d photogrammetric survey was carried out with the main purpose of producing rectified images of the architectural surfaces to be used for diagnostic investigations; to obtain this result it was useful to combine acquisitions from the ground with the acquisitions obtained from drone flights to solve some problems.

The photographic survey of the Verruca was particularly complex due to a series of environmental conditions that made shooting difficult: the greatest difficulties were encountered along the outer perimeter of the fortification, which, being on the top of a particularly rocky mountain, did not allow move easily around it to build a three-dimensional model; moreover, the vegetation around it, even if not particularly luxuriant after the fires, forced constant movements and changes of framing and definition on the wall surfaces, as well as causing considerable differences in lighting due to the filtering of light through branches and trunks. Beyond this, in some areas it was impossible to resume the wall texture due to the degradation caused by spontaneous vegetation.
The photographic shooting campaigns were therefore organized to solve these difficulties and to obtain a textured model that could describe the surfaces with a definition at least on a 1:50 scale.
In choosing the correct instrumentation to use for shooting, the condition of poor lighting was considered, which causes dazzling points of light where the sun's rays enter. For this reason, it was necessary to provide for the use of tools that were able to create high quality frames despite the light present being significantly unfavorable for photographic shooting. A full frame Sony A 7R Ⅱ camera (42.4 MP CMOS sensor) mirrorless was used, in order to guarantee a high level of definition, which was able to describe the walls in its details, and a frame of good quality at the level of exposure: this camera is able to return high quality frames even by setting a rather high sensitivity, in such a way as to encourage shooting without a tripod; the same camera body was mounted for drone shooting, on the Leica Aibot AX20 model. (Figure 3)

Figure 4. Three-dimensional model after the reconstruction integrated by laser scanner and photogrammetry.

To best reconstruct the surfaces of the fortress, it was decided to shoot frames following three levels of investigation: a first from the ground moving around the object at close range, a second plane shooting zenith images, a third still aerial but tilting the camera to shoot at best the elevations.
Each of these photographic sequences, shooting objects from different distances, required the use of lenses with different focal lengths. For the first sequence, from the ground, a Sony FE 28mm f / 2 28mm was used, ideal for moving around objects even at close distances, less than 2 meters: with this lens all the external and internal surfaces of the fortification were acquired. A Sony Zeiss Sonnar T * FE 55mm f1.8 ZA 50mm was used for the second and third sequence, rotating around the fortress at a more or less fixed distance.
The choice of the focal length was based on the study of the resolution that must be guaranteed to the frames in order to fall within the definition scales of the three-dimensional model; if, in the case of the laser scanner survey which is directly acquired in metric scale, it is possible to evaluate the definition on the basis of the set point grid, as regards the photographic survey, the evaluation of the definition values must be designed on the basis of the pixels with which the surfaces are defined. The photographic acquisitions maintained a ratio of at least 6px / cm with a minimum margin of overlap between contiguous frames of 50%.
9 targets were also positioned on the ground and the corresponding GPS coordinates were obtained, useful for scaling and georeferencing the point clouds.
At the end of the data collection phase, 682 final images were imported and oriented in the 3DF Zephyr software during the 3D reconstruction process. The photogrammetric point cloud was then joined to the laser scanner point cloud to obtain an even more detailed model, as well as scaled and georeferenced. (Figure 4)
Before proceeding with the data processing for the reconstruction of the three-dimensional scene, a careful quality control was made on the frames: although we had always tried to keep within the safety shutter speeds

Figure 5. Drawing of the plan of the fortress.

to avoid the blur effect in the photographic shots (Forti 2006), especially with regard to acquisitions from close distances in which, moving around the object, one incurs repeated changes in light exposure, the risk of having frames out of focus or with incorrect exposure had to be avoided. For this reason the frames in raw format have been imported into a special software with the aim of verifying their correct focus and adjusting their parameters. In this way, the white balance was equalized for all the shots so as to have a color as uniform as possible. Due to the different light exposures of the surfaces, it was also decided to limit the presence of over-lit and shaded areas to a minimum, reducing the Highlights and Shadow parameters to a minimum. Finally, we tried to make the exposure of the surfaces as homogeneous as possible by varying the parameter according to the shutter speed of the frame.The data from different acquisition systems were used to create the technical drawings (plans and sections) according to the traditional system that involves the extraction of the geometries from the laser scanner point clouds, the materiality of the surfaces from the photogrammetric acquisitions: both databases have been suitably subjected to data certification protocols in order to verify

Figure 6. Drawing of the access elevation to the fortress.

the reliability of both the registration of the scans and the calibration of the photoplanes on the point cloud (Pancani 2017). (Figure 5, Figure 6) The verification of the reliability of the reconstructions took place by comparing the different three-dimensional survey systems: the survey integrated different methodologies, producing multiple digital copies of the Verruca with different levels of reliability. We can synthesize the acquisitions in three different reconstruction systems: laser scanner, SfM and satellite. Two of these measurement methods are able to provide a measurement within certain error parameters: the single laser scan in fact, depending on the model of instrument, guarantees high reliability, in our case millimetric; in the same way, the GPS has guaranteed centimetric measurements on the xy plane; 1.2 cm on the vertical axis. Unfortunately, it is not possible to say the same about photogrammetric reconstructions, although the positioning of the trigger point is supported by the presence on the drone of a high-precision GPS: in fact, the positioning of the trigger point does not guarantee the correct reconstruction of the point clouds that are influenced. from numerous and different problems related to the light source (Pancani, Bigongiari 2019). For this reason, after an accurate control of the registration process, the laser scanner survey was taken as the morphological basis, whose polar coordinates were used to verify the control points of the photogrammetric survey, both from the ground and from the drone. At the same time, the union between laser scanner alignment and photogrammetry was experimented, obtaining interesting results in terms of reliability of the mesh model: together with the developers of 3d FLOW with whom a collaboration has been active since 2019, there is the intention to improve these algorithms for make the photogrammetric survey even more an integrated survey.

4. Conclusions

The Verruca survey made it possible to experiment with numerous data acquisition systems in order to integrate the results from the different instruments.
The three-dimensional model obtained by the drone, necessary for the reconstruction of reliable textures, has been verified to be reliable per cm compared to the laser scanner model. Highly reliable drawings were obtained which are useful for analyzing the state of conservation of the architecture; thanks to the use of the drone it was possible to measure points that were not accessible until now. The research on methodologies by the research group in collaboration with the software house 3d FLOW will be increasingly directed to the study of rapid systems that integrate the use of laser scanner and drone acquisitions to obtain increasingly reliable data.

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The use of UAVs is increasingly widespread in activities related to Heritage documentation. In recent years the development of methodologies of data integration, obtained through surveys that exploits drones to reach privileged observation points, has been witnessed by the numerous computation platforms, software and tools, that populate the exchange.
The definition of increasingly reliable methodologies and procedures of close-range photogrammetry has produced considerable results in the survey of Architectural Heritage.
Nowadays, several Universities and Research Centres, together with enterprises, are working to optimize documentation services whose goal is, in any case, the representativeness of technical data aimed at the project development. Parallel to aerial documentation, even the applications of remote-controlled terrestrial drone systems is renewing the inspection and survey practices in architecture and on territory, overtaking barriers and access dimensions to sites and emergency contexts otherwise impractical for human operators.
Surface rovers and submarine robotics, equipped with controlled cameras and implemented survey devices, in terms of stability and compartment, contribute to complete an extremely scientific and innovative field, where the central theme of robotics applied to Cultural Heritage documentation is expanded and consolidated in correspondence to the international categories of UAS (Unmanned Aerial Systems), USV (Unmanned Surface Vehicles) and UUV (Unmanned Underwater Vehicles). Drones, in the wider terms of their definition, are now used for documentation, management, protection, maintenance, and monitoring, integrating imaging systems and measuring instruments that contribute to define three-dimensional databases on Cultural Heritage. This conference is promoted with the aim of collecting recent experiences on that topic and of providing a moment of reflection between academic and enterprise realities for the promotion of updated frameworks for the development of research in the architectural survey field.

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