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APPLICATION OF INTEGRATED 3D SURVEY TECHNOLOGIES IN AN ETRUSCAN NECROPOLIS: THE CASE OF SASSO PINZUTO (TUSCANIA, VT)

1. Introduction

The Sasso Pinzuto necropolis is located along the eastern side of the Marta River southeast of the urban center of Tuscania (VT), on the western slope of the large *plateau* of San Lazzaro (Fig. 1). It represents one of the less investigated cemeteries in the area: the burial ground is flanked by a segment of an Etruscan road cut off in the tufa, connecting Tuscania with the hinterland of *Caere*, which in Roman times became the *via Clodia*. Due to its connection via this crucial communication route, the site experienced an uninterrupted occupation in ancient times. The chamber tombs currently visible belong to two main types: one type exhibits an upper fissure in the middle of the roof ('tombe a fenditura superior'), while the second one is entirely excavated in the tufa. The tombs entirely excavated in the tufa are the most numerous and display different types of plans. Most of them consist of single rooms, but there are also several tombs composed of two coaxial rooms. Generally, the typology of the two coaxial chambers is widespread in Tuscania and began in the late 7th century BCE. There are other hypogea with plans and characteristics of internal elements that suggest a dating mostly within the 6th century BCE, mainly influenced by models developed in *Caere* (Quilici Gigli 1969; Prayon 1975).

Limited and challenging-to-identify excavations were conducted on the site in the 19th century and the first half of the 20th century. Between the 1960s and 1990s, the Soprintendenza dell'Etruria Meridionale undertook targeted excavations, mostly aimed at recovering illicit and clandestine activities, which remained largely unpublished (Scardozzi 2012, 101-107). At the end of the 1960s, S. Quilici Gigli focused on the archaeological topography of the site, in the broader context of the archaeological map of Tuscania (Quilici Gigli 1970). G. Scardozzi made a valuable contribution to the documentation of archaeological evidence at Sasso Pinzuto (Scardozzi 2012, 2019), recording, systematizing and updating both legacy and newly acquired data (Fig. 2).

Within the research carried out in Sasso Pinzuto, a notably discovery occurred during the rescue excavations conducted by L. Marchese in April-May 1963. Fragments of molded clay plaques decorated with figure in relief were found, including one depicting a departing warrior moving right followed by two biga horses (Moretti, Ricciardi 1993, 177, fig. 46, 'scena di partenza II'; Sgubini Moretti, Ricciardi 2004; Winter 2009, 262, n. 4.D.4). In

Fig. 1 – The Sasso Pinzuto area (in white) in the context of Tuscania (Viterbo, Latium) on a satellite image (2023, Google Maps).

August 1994 the Superintendence, in collaboration with volunteers from the Gruppo Archeologico Romano (GAR) leaded by the late M. Incitti, decided to carry out a cleaning and documentation operation on a known *tumulus* in the area (Tumulus 1, see below). Further investigations were carried out in the 2000s by the Superintendence, leading to the discovery of new tomb contexts, culminating in 2020 with the first intervention by the Center for Ancient Mediterranean and Near Eastern Studies (CAMNES), based in Florence but already active in the Tuscania area, through the exploration of the 'Black Pigs' tomb.

A.N.

2. The 2022 excavation campaign

The 2022 excavation campaign investigated two areas of the necropolis of Sasso Pinzuto conventionally called the Northern and the Southern Areas (Fig. 3, A and B) (for further information about 2022 excavation see Naso *et al.* in press). In the Northern Area, the research started with Tumulus 1,

Fig. 2 – Aerial views A) on the archaeological site of Sasso Pinzuto with Tuscania in the background; B) on the Area B investigated in 2022 campaign.

already investigated in 1994 by GAR. The chamber tomb contained in Tumulus 1 (approx. 10 m in diameter) is a hypogeal tomb totally dug into the tufa and it follows a typology derived from models developed at *Caere* in the late 7th century BCE with a transversal *atrium* and three chambers excavated on the back wall (Naso 2023) (Fig. 4).

The tomb, called 'tomba Incitti' in honour of M. Incitti, had been already violated in ancient times, but the excavation made possible the recovery of remarkable finds: some ceramics of Etruscan production (bucchero and Etruscan-Corinthian amphorae from the Monte Abatone Group), imported (Attic Black-figure and East-Greek vases), and few metals including a gold braid clip. According to the architectural typology and the materials found during the GAR excavation in 1994, it is possible to hypothesize a chronology around the first quarter of the 6th century BCE. A small 'fossa' grave was found intact and recently published by A.M. Moretti Sgubini, belonging to a newborn child (Moretti Sgubini 2018). The grave was located on the

Fig. 3 – Sasso Pinzuto-Tuscania (in white): in the context of the river Marta Valley on a historical aerial photograph georeferenced in GIS; in white dash dot line, A) the Northern Area; B) the Southern Area.

southern side of the *dromos* and originally covered by a tufa block; according to the objects found inside, it may be dated to around the second quarter of 6th century BCE.

During the 2022 excavation around the *tumulus* have been found some fragments of molded decorated clay slabs, in particular one fragment with riders (finds from Tuscania, Ara del Tufo: Moretti, Ricciardi 1993, 169, figs. 25-26, 'cavalieri al passo II') and other fragments with rests of a biga including horse paws and wheel (Moretti, Ricciardi 1993, 169-175, 'scena

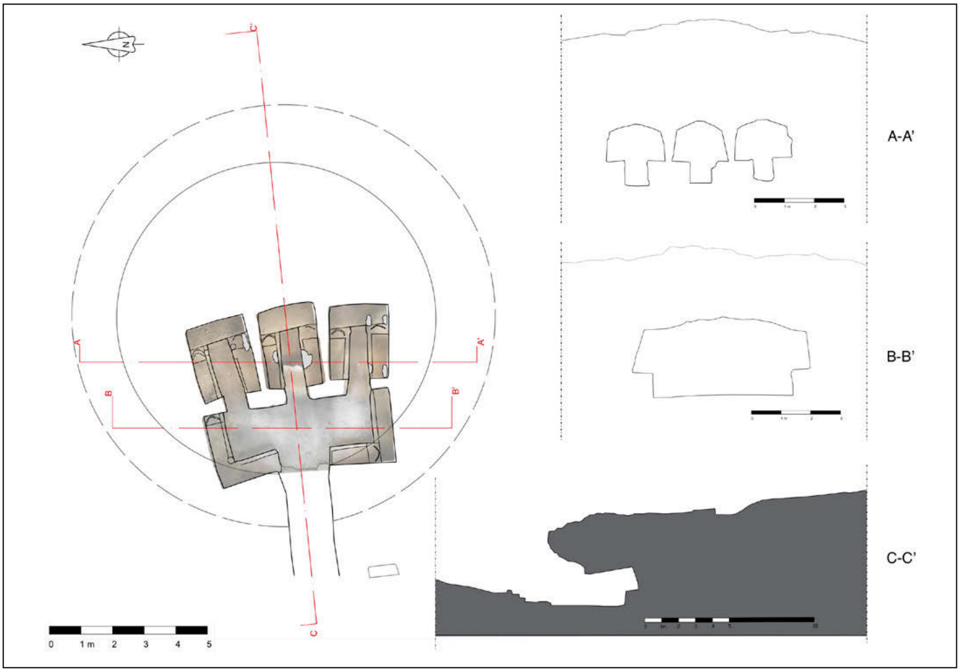

Fig. 4 – Tumulus 1, Sasso Pinzuto-Tuscania: tomb plan and sections with the chambers' orthophoto plan. The crepis of the *tumulus* is not entirely excavated.

di partenza I'). Worth mentioning are also fragments with painted *guilloche* in the white-on-red technique (Winter 2009, 94, fig. 2.6.a, *guilloche* A).

In the Southern Area – a small plain about 90 m from the Northern Area – four fossa graves (n. 126, 127, 128, 130) and two chamber tombs (n. 125 and 129) were excavated. The *fossae* correspond to two types: one has a simple profile (n. 126 and 128), and the other characterized by a more complex profile of deeper level (n. 123 and 130). All tombs were violated but it was possible to recover small finds of personal equipment that had escaped from the illegal excavations. In Tomb 126 a fibula type Lo Schiavo 142 (Lo Schiavo 2010, 310, tav. 151) establishes the chronology within the 7th century BCE; Tomb 127 yielded a thin fibula with a rhomboidal profile, type Lo Schiavo 183 (Lo Schiavo 2010, 416, tavv. 229-232). In the small fossa 128 (approx. 90 cm long and 30 cm wide), a small cushion in relief had been cut into the inner surface. Although the burial did not yield any funerary equipment, the dimensions suggest that it belonged to an infant, and shows in this sector the presence of tombs reserved for both infants and adults, perhaps member of the same family. In chamber Tomb 125, belonging to the coaxial type, some elements, with special regard to impasto lenticular ribbed spindle, allow us to establish that at least one female figure was buried here. Some complete vases belonging to bucchero drinking sets (*kyathoi*, cups, chalices, *kantharoi*, *oinochoe* and a small jug) have been also found.

Particularly significant on a stratigraphic level is the discovery of a layer composed by dense, dark clay, with plastic consistency, positioned in the vestibule of the tomb near the entrance door. This can be interpreted as a waterproofing arrangement, functional to the sealing of the chamber and to avoid water infiltrations. The preliminary results of chemical analysis of samples carried out by C. Rispoli, Dept. of Earth Sciences, University of Naples Federico II revealed that some minerals have been intentionally added to the natural clay to increase its waterproof properties.

Chamber Tomb 129 has a cruciform plan with a *dromos* and vestibule featuring a tufa seal, made of two overlapping quadrangular slabs resting on two monoliths, both positioned at the end of the *dromos*. Some iron objects such as spearheads, javelin heads, *sauroteres*, a knife and a spit were found along the steps of the *dromos* and they can be interpreted as a possible ritual offering after a reopening of the tomb. On that occasion, the tufa slabs were placed in the vestibule and some clay vases were moved in front of the entrance door. The vases consist of Etruscan-Corinthian pots (two *amphorae*, a figured *alabastron* and additional balsam flasks painted with linear decoration), bucchero (chalices, *kantharoi*, cups, *oinochoai* and *olpai*) and impasto vases (jars and bowls). Two trade amphoras respectively from Samos and Chios along with an Attic *floral band cup* date the deposit no later than 530 BCE (*CVA* Adria: Bonomi 1991). In the chambers, some elements shed light on the people buried in the tomb. In the left-side chamber, fragments of iron sandals and a scarab from Naukratis (Hölbl 1979, 142, tav. 95, 6-7; 96, 8-10; Gorton 1996, 96, fig. 20, 3 from Perachora, 98, 123-124) ensure that at least one woman was buried here; in the right-side chamber, a rare protome of a ram and a small paw both in bucchero belong to rare objects to interpret probably as special commissions for the tomb's owners.

M.Z.

3. The topographic survey project

The site's geomorphology is mainly characterized by extensive outcrops of so-called 'red lithoid tuff with black scoria', in which the Etruscan funerary landscape as well as the Roman and Medieval occupations phases were carved out. In the last century, the archaeological landscape was re-shaped by the agricultural exploitation, which intensified in the entire area after the Second World War (Scardozzi 2019, fig. 6). The changes occurred in the local landscape could clearly be deduced from the comparison between

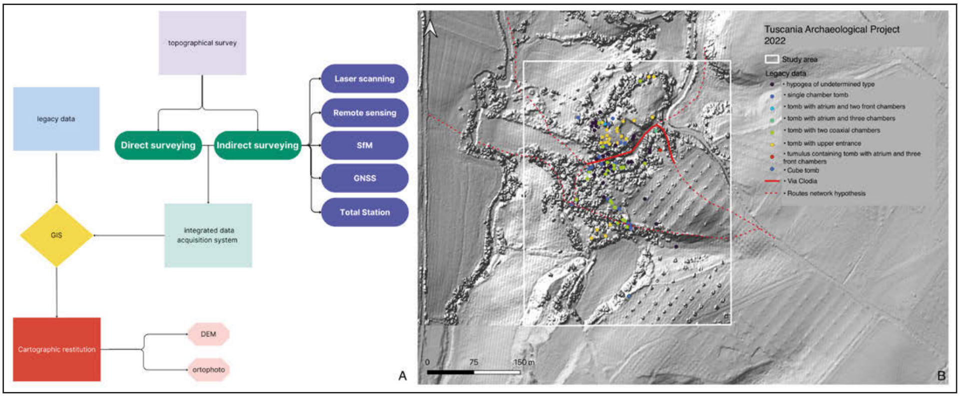

Fig. 5 – A) Diagram of the topographic data integration process; B) Sasso Pinzuto-Tuscania (in white): archaeological legacy data available for the site pletted on a topographic basis obtained from a 1 m LiDAR Composite DTM (2013, Ministero dell'Ambiente e della Tutela del territorio e del mare) in the GIS created for the project.

historical aerial photographs, satellite images and m1 Airborne LiDAR Data (ALD) obtained by the Italian Ministry of the Environment[1]. The latter one was visually interpreted using image blends of LiDAR visualizations (VAT method) based on in-house-generated digital terrain models carried out in the Digital Archaeological Mapping Lab (University of Naples) (Fontana 2022; Brancato *et al*. in press) (Fig. 5, A).

The archaeological research project at the site started in June 2021 with the topographical survey[2]. In the plan design phase, special attention was paid to the integration of different methods in terms of complexity, costs, and yield, both for the acquisition and visualization phases (Pansini *et al*. 2018; Brancato *et al*. 2023). Preliminarily, all new and legacy data were stored, annotated, georeferenced and vectorized in a Geographic Information System (GIS) platform (Bogdani 2020). As it is well known, GIS serves as a

[1] Acquired by the Italian Ministry of the Environment (Ministero dell'Ambiente e della Tutela del territorio e del mare) during the first phase of the Extraordinary Plan of Remote Sensing (Piano Straordinario di Telerilevamento Ambientale) between 2008 and 2013, the ALD are accessible as WMS through the Italian Geoportale Nazionale (https://gn.mase.gov.it/portale/servizio-di-consultazione-wms): Costabile, Cocco, Petriglia 2013; García Sánchez 2018.

[2] The paper presents the preliminary result of the on-site field workshop '3D Archaeology. Tecnologie e strumenti digitali per la conoscenza del paesaggio, 01.07.2022, Tuscania (VT)' organized by R. Brancato, A. Naso and M. Zinni, with the participation of G. Scardozzi (CNR-ISPC) and S. Amici (Leica Geosystems): the students (L. Ceruleo, C. De Simone, L. Fusco, G. Giorgio, G. Luongo, D. Moschetti, A. Neri, C. Pianese, O. Proietti) selected for the intensive course were actively engaged in all the activities, from data acquisition to data processing, yielding relevant and promising results (http://www.ssba.unina.it/?p=1283).

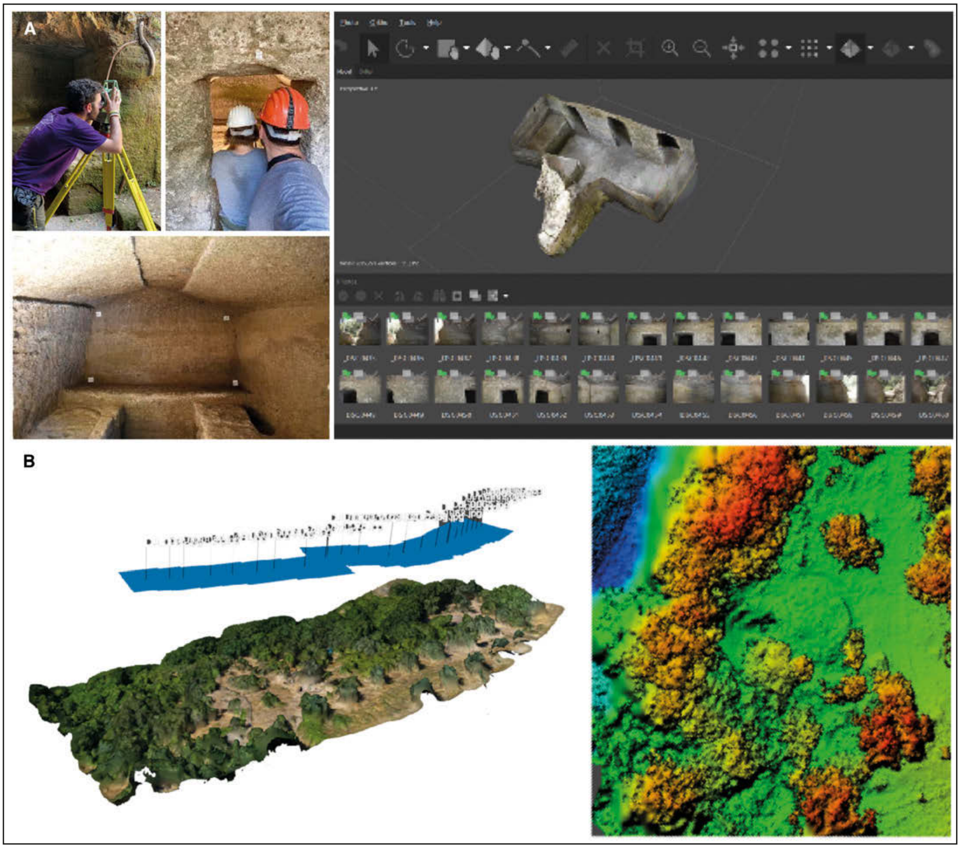

Fig. 6 – Sasso Pinzuto-Tuscania: workflow followed for SfM modelling: A) on-site photo capturing inside Tumulus 1, a snapshot of Agisoft Metashape software, showing the position of the images, photo alignment, and camera settings, the location of GCPs; B) UAS-Based Photogrammetry, photo alignment the Agisoft Metashape project, the dense point cloud and the DTM finally obtained (right).

digital platform that seamlessly integrates and visualizes archaeological data, aligning it with its topographic and semantic meaning (Fig. 5, B).

The digital topographic survey methods applied at Sasso Pinzuto were precisely calibrated to ensure efficient and high-quality documentation tailored for the technical analysis of archaeological structures. Given the complex multi-level layout along the southern slopes leading down to the 'via cava', coupled with dense vegetation coverage, a thorough survey approach was imperative for the execution of the planned activities.

In addition to the direct surveying of each tomb, a comprehensive digital topographical survey was planned for the entire area and the sectors involved in the 2022 campaign (North Area, Fig. 3, A; South Area, Fig. 3, B), utilizing an integrated data acquisition system that included: 1) Structure from Motion (SfM) technology; 2) close-range remote sensing with unmanned aerial vehicles (UAVs); and 3) both static and mobile laser scanning. Indirect surveying was strategically planned to utilize conventional topographic instruments (Total Station, GNSS antenna)[3] to capture functional topographic points essential for cartographic restitution in archaeological research. Celerimetric survey operations were conducted in the area, leading to the establishment of an open-type topographic polygon. This choice was informed by the need to navigate the challenging visibility issues caused by dense vegetation on the *plateau's* summit, especially on the northern slope.

The instrumental survey was designed to produce high-resolution digital cartography for the entire site (geometric model) and to provide a topographical foundation for 3D models, addressing the needs of research, conservation, and enhancement within cultural heritage studies (Lock 2003; Moscati 2009; Ferdani *et al.* 2019). Multi-scalar 3D digital models were created – and integrated – in photogrammetry software platforms (Agisoft Metashape; Leica Cyclone) (Fig. 6, A). The digital images and 3D spatial data derived from photogrammetric processing were georeferenced using the WGS 84 UTM Zone 32N system (EPSG 32632). This was achieved through the identification in the images of Ground Control Points (GCPs) utilized for the placement of total station and precisely measured with the GNSS antenna. On the basis of the same GCPs, through the 'Georeferencing' plugin available in the cartographic software QGIS, each vector and raster file was then georeferenced and integrated as layers in the GIS platform.

Boths the tombs previously investigated and the new contexts unearthed during the 2022 campaign were documented using a digital camera (Sony α6000 with APS-C 24.3 MP). To maximize the documentation quality and definition, photographic surveying was conducted by an operator and, when necessary, using a calibrated telescopic pole. In order to understand the relationship between each individual tomb and the entire context of the Sasso Pinzuto necropolis, a comprehensive photogrammetric survey of the investigated area was also planned.

Proximity remote sensing of the entire area (ha 14,262) was carried out through systematic aerial surveys using a quadcopter drone, piloted by an operator (Fig. 6, B). Captured periodically throughout the project, the aerial imagery was integrated with the other topographic measures used for the survey project by recording the three-dimensional coordinates of the GCPs clearly identifiable in the aerial photographs. The proximally sensed data

[3] Total station TS03 5' R500 Leica; GNSS Leica FLX100.

were used for the creation of an ultra-high-definition digital model (1.2 cm per pixel), from which it is possible to extract not only photo plans but also an updated topographic base with 10 cm contour lines.

Across both micro (e.g., the chamber tomb) and macro (the necropolis area) scales, the 3D digital survey was carried out with students actively participating also in the data processing, which took place during the excavation campaign. Data collected at different scales were seamlessly integrated into a workflow designed to generate three-dimensional and two-dimensional models (Fig. 5). This process, based on the systematic application of SfM techniques, enables the extraction of orthophotos for plans and sections from the obtained Digital Elevation Models (DEMs) (Bezzi *et al.* 2010). Indeed, the multi-scalar 3D models produced allow for the extraction of digital objects that can be employed in archaeological topography across various scales of representation: these include comprehensive, detailed, and georeferenced orthophoto plans, sections, and axonometric projections.

R.B.

4. The laser scanner application

In Sasso Pinzuto, 3D laser scanning technology was tested through the so-called RC (Reality Capture) technology in both static (on a tripod) and dynamic (mobile) formats. Indeed, two different laser scanners were used: the static Leica BLK360, characterized by its compact dimensions (16×10 cm), making it suitable for confined scenarios such as hypogean contexts, and the mobile Leica BLK2GO, distinguished by its portability and the integration of SLAM-derived robotic technology (Simultaneous Localization and Mapping), IMU (Inertial Measurement Unit), and VIS (Visual Inertial System) platforms (Fig. 7). These sensors, collaborating within a dedicated GPU, enable the dynamic calculation of station coordinates. The scanning process starts on a passive base serving as the emanation center (x, y, z with a value of 0). The GRANDSlam, a combination of the three aforementioned sensors, continuously calculates the movement and changing position of the instrument's phase center, defining the 3D trajectory on which the coordinates of the 420,000 points/sec emitted by the on-board LiDAR are calculated. Additionally, three on-board low-resolution cameras capture a triad of photos used to directly color the 3D model with the recorded RGB value and enable the VIS calculation of the trajectory. The result is a cloud recognizable in a single setup, in a local reference system, identifying all points encountered along the performed (and estimated) 3D trajectory.

The resulting product of the scan is a set of points, formed by a cloud of x, y, z coordinates in a local reference system defined by the instrumental axes, with the emanation center corresponding to the rotating prism's

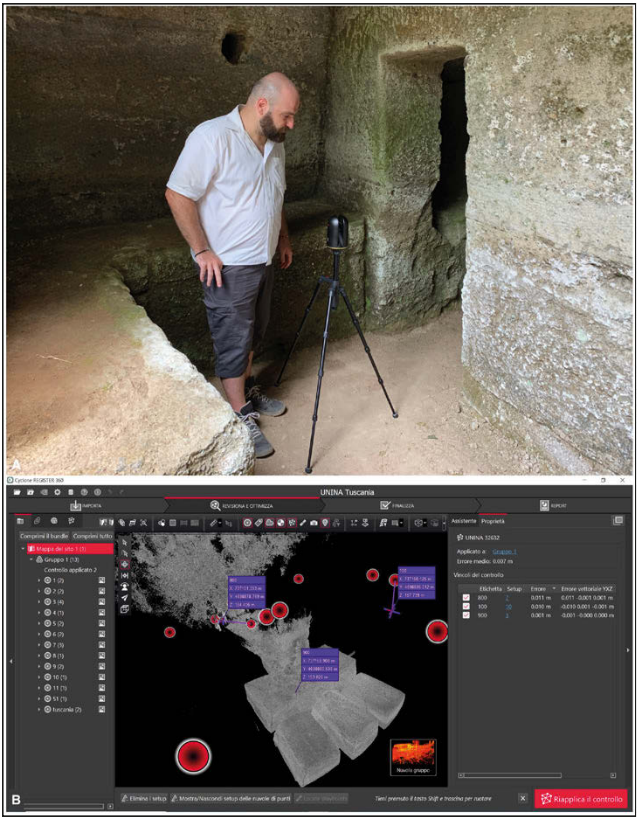

Fig. 7 – Tumulus 1, Sasso Pinzuto-Tuscania: A) setup 2 scanned with the BLK360G1; B) georeferencing by Gruppo Nuvola with GNSS and TPS measurements.

position. Reflectance is defined by a set of parameters calculated each time, as the laser return quantity is linked to various aspects such as the angle of incidence with the reflecting surface, temperature, color, detected material, albedo (the material's ability to reflect or absorb electromagnetic waves), humidity conditions, etc. Color information is acquired by on-board cameras, with varying resolution depending on the chosen model, calibrated to know the distortion and position values of the obtained equirectangular image, so it can be adapted to the spherical point cloud, coloring the geometric point according to the RGB value averaged from the photographic data.

In the case of the Tumulus 1 of Sasso Pinzuto, two phase modulation laser scanners were employed, which are very fast in the acquisition phase but adequately accurate for the survey's purposes. The static BLK360 laser

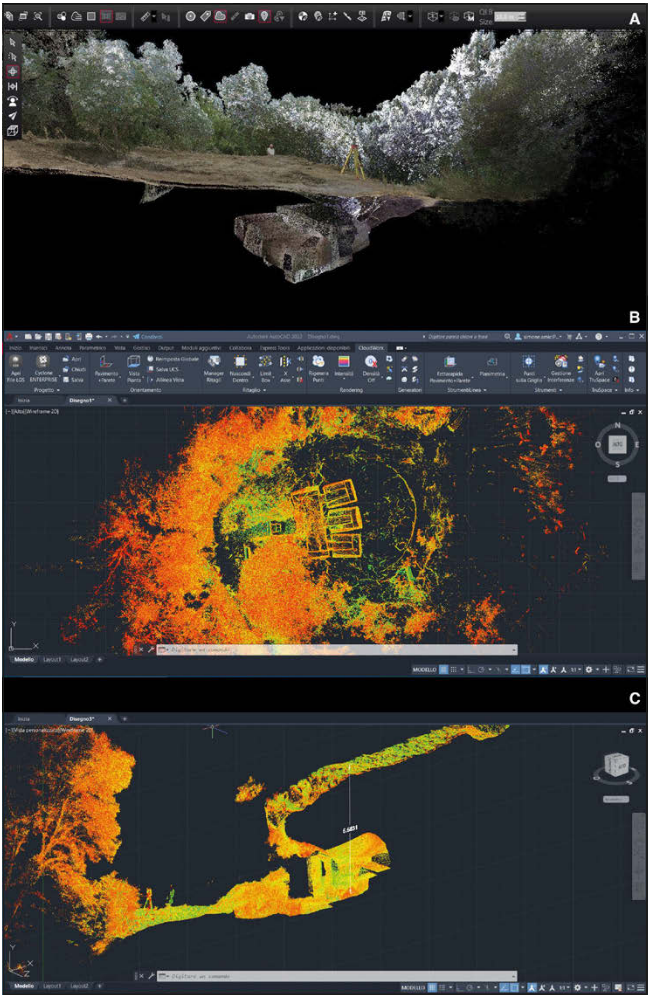

Fig. 8 – Tumulus 1, Sasso Pinzuto-Tuscania: A) Group Point Cloud deduced from static and mobile LS union; B) cloud data that can be vectorized within CAD software; C) section with height dimensioning between the walking surface of the central chamber and the external surface.

scanner was used inside the Tomba Incitti: 12 high-resolution setups (5mm @ 10m) with LDR photos were carried out, with an acquisition time of 4 minutes and 20 seconds for each scan. Scans covered the internal chambers (1 scan per chamber), the *atrium* (3 scans), the access *dromos* (2 scans), and what remains of the upper cap of the *tumulus* (4 scans), aiming to obtain

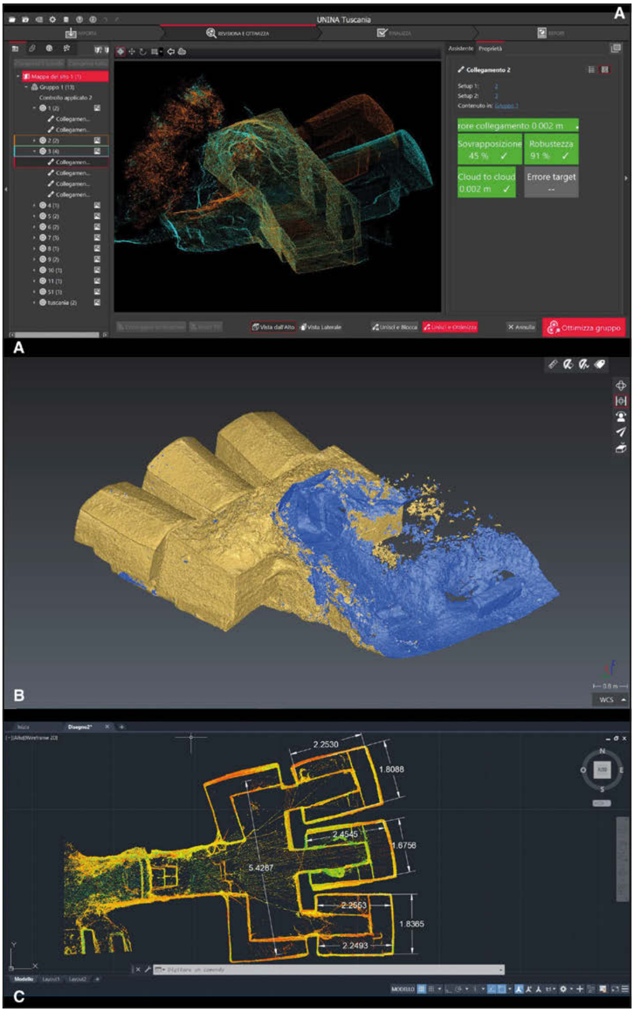

Fig. 9 – Tumulus 1, Sasso Pinzuto-Tuscania: A) registration process between two cloud setups; B) 3D modeling separately from the cloud data; C) point cloud dimensioning at 1:1 scale.

a single point cloud group for extracting geometric information useful for reconstructing plans, elevations, and sections of the investigated object. The three-dimensional data was also georeferenced according to the reference system by recognizing the topographic nails used for the positioning of the total stations from which the open framing polygon was derived, also duly measured using GNSS instrumentation (Figg. 7-8).

The closed and well-defined geometry of the Tomba Incitti was selected as a reference point for the mobile survey conducted with BLK2GO: once the instrument was initialized, by walking inside each desired geometry (internal chambers, *atrium*, *dromos*, upper cap of the *tumulus*, connecting path between the two areas of the necropolis, and South Area), it was possible to map this large portion of the necropolis in less than 10 minutes. After completing the acquisition work, the Cyclone Register 360 software was used to download and verify the obtained data: dynamic sections on the x, y, and z axes (slices) were used to verify the quality of the registration that did not require the use of targets for any of the phases, but only the real-time acquired point cloud data. The resulting survey is a blend of geometric data with very high accuracy, linked to photographic documentation that the current state of the locations at the time of the survey. The next step was to export a single 'frozen' cloud in the desired coordinate system, imported into the Cyclone 3DR modeling software (Fig. 9).

This program allowed not only the creation of a continuous mesh of the obtained geometric data (subsequently textured using equirectangular images directly obtained from the instrument) but also the comparison and analysis of geometric deviations (Δx, Δy, and Δz) recorded between point clouds (e.g., the same tomb acquired with static and mobile instrumentation), between clouds and meshes (to verify different triangulation parameters used), between meshes or polylines. The use of these different geometric natures – points, lines, and surfaces – opens a new field of application for Cultural Heritage that is still little practiced today, that of the so-called geomatic monitoring. Through laser scanner technology, it is equally possible to acquire a specific archaeological dataset, both in geometric and photographic terms, comparing and modeling it for knowledge as well as preservation purposes: through acquisition over time, perhaps following a defined programming, it will be possible to monitor the 'health' status of that Heritage, highlighting any critical areas and narrowing down the field to portions affected by wear or detachment, all simply by comparing point clouds or 3D models acquired at different times.

S.A.

5. Final remarks

The work at Sasso Pinzuto revealed once more how significant can be the research on sites known through rescue excavations and never systematically investigated. The re-opening and cleaning of chamber tombs explored by illegal excavators yielded valuable finds and gave new information about tomb architecture and decoration including wall painting. The new finds at Sasso Pinzuto help to define the cultural features of Tuscania

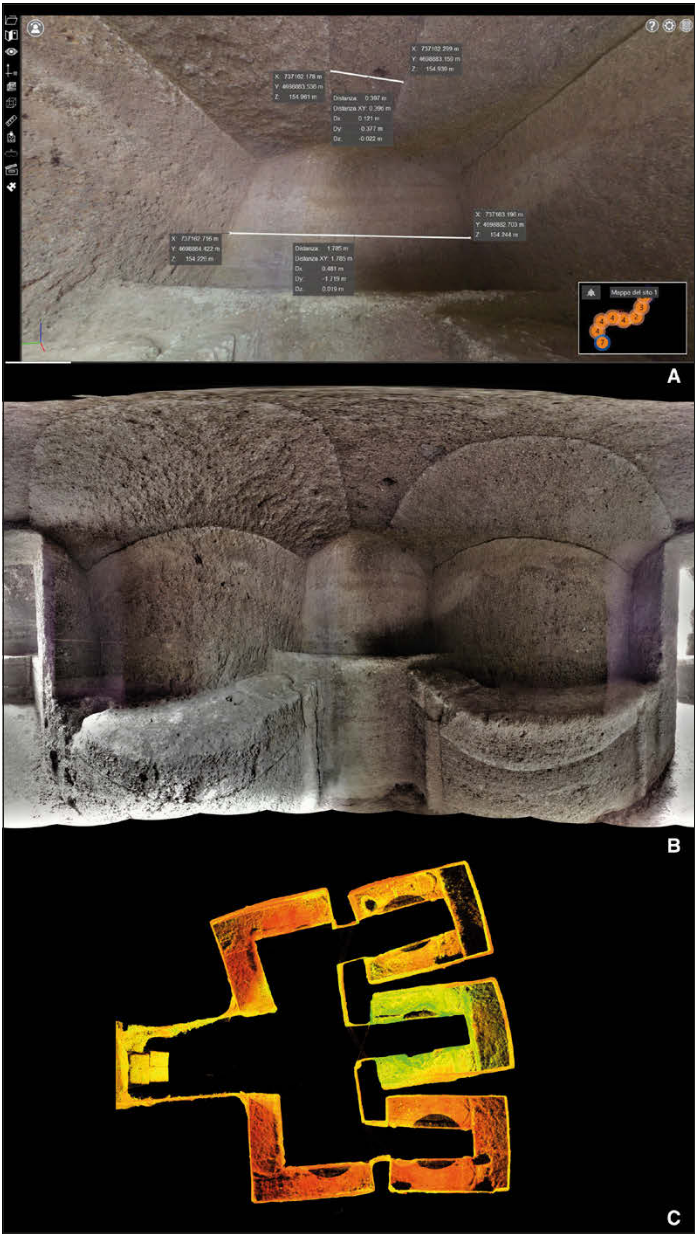

Fig. 10 – Tumulus 1, Sasso Pinzuto-Tuscania: A) spherical RGB image measurable with Point Cloud; B) equirectangular image extracted from the scanner for documentation purposes; C) point cloud group sectioned at the height of the funeral beds.

in 7th and 6th cent. BC and confirmed the local development of funerary cults inside the cemeteries areas. The cults are revealed by the clay slabs belonging originally to timber building(s). The plaques fragments are so distributed on the ground that one can hypothesize a deliberated destruction of the building(s), whose scanty rests have been further scattered by later agriculture activities.

Moreover, the research experience at Sasso Pinzuto did help in defining an efficient 3D integrated protocol for topographic digital data collection and revision in an archaeological site characterized by poor visibility, notable areal (both indoor and outdoor) development and complex geomorphology. In comparison to the so-called digital photogrammetric technology and SfM application, laser scanners prove to be superior in terms of quality regarding the obtained geometry. Indeed, a range-based sensor is better suited to replicate and record complex surfaces, such as excavated tombs. Additionally, this technological tool is the only one applicable in contexts completely devoid of natural light, such as underground scenarios. From a colorimetric perspective, however, highly valued by those working in the field of Cultural Heritage, the point cloud and the resulting texture obtained on the calculated mesh fall short in comparison to that computed through SfM procedures (Fig. 10).

As highlighted in the 2022 report activities, the team involved in the new topographical survey of the site was able to channel the best that each technology can offer within its work, from macro-to micro-scale. Indeed, in Sasso Pinzuto, the use of the most advanced methods of 3D acquisition and modeling allowed for the representation of archaeological features through the creation of digital models that combined the graphic representation capabilities of images (typically used for documentation) with the precision of topographic surveying. By adopting an integrated approach involving legacy data GIS integration, direct survey, digital photogrammetry and 3D laser scanning (Cardaci *et al.* 2013, 221-226), it was possible to obtain a high-definition three-dimensional multi-scale digital model of the whole area, from the entire cemetery to each chamber-tombs.

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ABSTRACT

The aim of this paper is to present the results of the research undertaken through a series of on-site surveys (2021-2023) at the Sasso Pinzuto site, located approximately 1 km SE of Tuscania (Viterbo, Italy). Situated along the eastern side of the Marta river valley, the necropolis layout is little known but it is extensive, including ca. 100 rock-cut chamber tombs. The 2021-22 archaeological campaigns started with a new topographical survey of the site and investigated two areas conventionally defined the Northern and the Southern Area. In the Northern Area, specifically within the vicinity of Tumulus 1, fragments of mould-decorated architectural plaques from a building discovered. In the Southern Area, a small *plateau* about 90 m from the Northern Area, four burial graves (n. 126, 127, 128, 130) and two chamber tombs (125 and 129) were excavated. This study sheds light to the great potential of applying digital technologies for a new understanding of the Etruscan tombs. Indeed, by using various non-destructive prospecting methods (aerial photogrammetry, fieldwalking survey, architectural drawings), coupled with precise location using RTK GNSS, and integration of legacy data in GIS, the site underwent a comprehensive reexamination.